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GEOPHYSICAL PROSPECTING

Official Journal of the
European Association of Exploration Geophysicists

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OF
VOLUME V
1957

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PURPOSE OF ACCIDENT REPORTS AND STATISTICS *

BY

H. RICHARD**

member of the E.A.E.G. Safety Committee

Abstract

The President of the E.A.E.G. Safety Committee has stated that European geophysicists fail to attach sufficient importance to accident statistics. Nevertheless these statistics are the best means at our disposal for the study of the factors influencing the number and severity of accidents.

It appears essential that two points should be stressed, firstly that the accident reports must be completed correctly, and secondly that the interpretation of each report and of the statistical data must be done systematically.

If these conditions are fulfilled it should be possible to create, at all levels, a technical and psychological atmosphere which would do much to protect geophysicists against accidents.

Purpose of Accident Reports and Statistics

The President of the Safety Committee of the E.A.E.G. has stated with regret that European geophysicists do not give the importance they deserve to statistics of accidents. Those who earnestly wish to improve safety must have at their disposal a complete network of information which will allow them to study the factors influencing the number and severity of accidents.

As a member of the Safety Committee, it appeared to me that it was my duty to call the attention of all geophysicists to the important part played by statistics. However there are only effective when they satisfy certain conditions. Accident reports must be correctly drawn up by the foreman and checked by the supervisors, technicians, etc. The information which they contain must be evaluated immediately. Finally all the numerical data must be grouped carefully and interpreted objectively.

Drawing up of Accident Reports

Accident reports must be drawn up according to the rules given below:

1) All accidents involving the loss of more than one working day must be taken into consideration. This rule must be followed absolutely. An analysis

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*) Presented at the Eleventh Meeting of the European Association of Exploration Geophysicists, held in Milan, 12-14 December 1956.

**) Compagnie Générale de Géophysique, Paris.

of the circumstances, even in minor cases, is often instructive in that steps can be taken to avoid the recurrence of more serious accidents.

A systematic survey of minor accidents, even accidents leading to no loss of time, is conducted by certain companies. American companies sharing in the safety programme of the S.E.G. take all accidents into consideration without exception.

From a financial point of view it should be borne in mind that an accident always causes an actual interruption of work which may last a quarter of an hour or more, even if it does not appear in the reports.

2) Immediately after the accident, the responsible chief must compile a complete report giving (a) *the name*, occupation, age, length of service, and experience *of the injured person*, (b) *the technical causes of the accident*, and (c) the human factors which exercised an influence.

The technical causes can be listed as

(a) Machines—indicating precisely the part: engine, transmission, hoisting device, etc.
(b) Vehicles—the type of vehicle, its mechanical condition, speed, and any infringement of the rules should be given.
(c) Explosion and fire
(d) Toxic, burning and corrosive substances
(e) Electricity
(f) Fall of the workman
(g) Stepping on loose objects or collision with obstacles
(h) Falling objects
(i) Caving of excavations
(j) Handling of heavy gear without mechanical devices
(k) Power-driven hand tools and non-power-driven hand tools
(l) Animals
(m) Miscellaneous causes.

Human factors which exercised an influence will include inattention, lack of training, indiscipline, unsuitable clothing, inadequate safety measures; the age, fatigue, and state of health of those involved, etc.

Injuries

The injuries are classified according to their *location*: head, trunk, upper limbs, lower limbs, general injuries; and according to their *nature*, such as shocks and concussions, wounds (including grazes, cuts and lacerations), burns, stings, dislocations, fractures, sprains, loss of a limb, asphyxia, immersion and other miscellaneous injuries.

Extent and degree of disablement

A distinction should be made between accidents of a fatal and non-fatal nature, and those resulting in a temporary and a permanent disablement.

3) Besides the copies forwarded to the administrative head, one copy of the report should be sent immediately to the Safety Engineer of the company. It is his responsibility to take steps to classify the documents, to recommend further enquiries, to keep the statistics up to date and to analyze the reports in close co-operation with the technicians.

Verification of Accident Reports

As soon as they are received all accident reports must be subjected to critical study, for the following reasons:

a) In practice the cause of accidents is technical, or due to some human factor. One must, therefore, oppose as strongly as possible the very widespread temptation to lay the blame on fate, or mischance... a temptation which prevents enquiries from being pursued far enough and irremediably distorts the statistics.

b) The precise technical causes or the human factors involved do not always appear at the first scrutiny, and errors concerning the cause of the accident are often made. About 10 to 20% of accident reports require further information.

c) It is to be feared that some of the objectivity of the first inquiry may be lost due to unwillingness to assume responsibility.

Function of the party chief: The party chief should pay special attention to the drafting of accident reports. During regular sessions devoted to safety it is part of his duties to discuss the causes of all accidents which have taken place in the party and to explain how they could have been prevented.

On such occasions he should not fail to stress to his personnel that the use of suitable tools, the proper unkeep and checking of the equipment are important requisites in accident prevention. Periodic and preferably weekly meetings should become a general routine as they remind everyone of his responsibility.

Function of the supervisor: Even the smallest operator knows very well that, through wide geographic distribution, the diversity of technical problems and the remoteness of the central administration, the conditions of geophysical work differ widely from those in a factory workshop. If these peculiar circumstances are not taken into account, supervision by notes, reports and accounts might become misdirected. It is part of the functions of the supervisor to keep close personal contacts with the parties, to discuss accident reports on the spot and to participate actively in the enquiries. In safety matters strictness on the part of the supervisor must be demanded.

Function of the safety engineer: In a business concern it is the foremen, party chiefs, supervisors, etc., who are answerable for safety and not the safety engineer or the safety department. The latter can only centralize information, instigate and follow up enquiries, but they are not responsible for the manner in which their proposals are carried out.

In short, the safety service acts as a counsel, as B.W. Sorge has pointed out in "Geophysics" of July 1954.

CONCLUSIONS FROM THE ACCIDENT REPORTS

After errors or omissions have been corrected and the necessary clarifications obtained, conclusions must be drawn, before filing the document. It is essentially a matter of deciding if steps of a technical or human nature should be taken. A number of questions, of the type given below, will arise:

Was the material in good working order?

Was the equipment provided with the regulation protective devices? Are other precautionary measures required, or should stricter regulations be made?

Was the supervision exercised by the party chief, headdriller, etc., adequate?

Were the regulations to wear gloves or helmets carried out? Was the footwear used suitable for the conditions?

Was the injured person too young or too old for the kind of work, and was he sufficiently trained, directed or experienced?

Had the injured person been previously involved in accidents; was he, in spite of misleading appearances, unfit to drive a heavy vehicle, handle a drill?

Was the shooter careless or distracted?

It can never be sufficiently stressed that certain accidents have a test value. They show up the defects of an organization, the failings of a certain type of material, or the shortcomings of a working method. In short they are a direct source of progress and economy.

As soon as a report leads to the conclusion that a piece of equipment or a working method should be altered, instructions must be given immediately.

First example: Let us suppose that an accident gives reason for suspecting the strength of the welding of the ring used to raise the portable mud pit. This is a warning of a break-down hazard which may have serious consequences and it would be unpardonable if a systematic check of the strength of those weldings did not take place at once.

Second example: One or more accidents appear to be related to the lack of reflexes of an employee. Such conditions demand an aptitude test. It might be as well to recall here that such tests have two main objects: to disclose accident-prone individuals and to improve recruiting.

a) Observation has clearly established the important part played by accident-prone individuals in the origin of accidents. The purpose of aptitude tests is precisely to disclose psychological qualities or defects, by means of tests adapted to the evaluation of specific mental functions such as level-headedness or the quality of reflexes. These methods allow the identification of individuals who are unfit for certain jobs.

b) In recruiting matters, the method of aptitude tests should be applied to the selection of applicants for jobs as drivers, drillers, etc. The method is much in favour at the Société Nationale des Chemins de Fer Français (French railroads) and should be put into general use in the geophysical industry.

Setting up Statistics

The better the reports have been drawn up and checked, the easier it is to establish and analyze the statistics. The findings should be classified according to technical cause, human factor, nature of injuries and degree of disability.

It is desirable that statistics be grouped according to geophysical methods in which hazards are of a similar nature, such as electrical methods, gravitational or magnetic methods, seismic refraction and reflection methods, and seismic drilling.

When the bulk of the statistical data is sufficiently large, the frequency of the hazards can be estimated in as uniform a manner as possible.

Distinction should be made between *the index of frequency*, i.e. the number of accidents per million working hours or some similar unit, and *the index of seriousness*, i.e. the number of working days lost on account of accidents per 1000 working hours. In case of death or permanent disability the time lost is generally estimated at 6000 to 7000 working days. It follows, and this is very important, that the value of the index of seriousness depends above all upon the number of serious accidents and particularly on the number of fatal accidents.

In order to give a rough estimate of the hazard in reputedly dangerous industries we point out that in France during 1955 there was 1 death per 1000 employed in coal mines (underground), 0.65 death per 1000 employed in iron mines (underground), and 0.5 death per 1000 employed in quarries. Are we sure that the danger involved in geophysical work is lower?

The two indices do not give an answer to the same question. The *frequency* is an unweighted index allowing the classification of accidents into a great number of categories, leading to general conclusions as, for example, a particularly dangerous type of vehicle, the causes of accidents by vehicles, the most dangerous occupations, and the most prevalent types of accident or injury.

The *seriousness* has a more human significance. As it is above all concerned with the frequency of fatal accidents, which are relatively uncommon, its violent variations are not always related to improvements or otherwise in safety precautions. It becomes therefore significant only over long periods of time. Computed over shorter periods, say one year, it reminds the responsible leaders of the value to be attached to human life. It makes an impression upon the personnel and warns them to be more careful.

From the business point of view, the index of seriousness is generally admitted to be more representative than the index of frequency, though this is not certain, because the real costs of minor accidents are sometimes considerable even when injuries are relatively light.

A truly quantitative interpretation of statistics is possible only when a sufficiently large number of accidents is considered. With man-power attaining several thousands, the railroads, coal mines, etc., provide a first-rate field of observation because they form homogeneous aggregates particularly suited for statistical investigation. It is then easy to study the effectiveness of safety measures, to measure the results obtained by training personnel, and to interpret clearly the trends of the indices of seriousness and of frequency, while taking into account the diversity of occupations and changes in methods. It is even possible to follow closely the effect on safety caused by the introduction of a new piece of equipment into service, the check on maintenance, and the check on manufacturing. In rail transport it is even possible to establish a divergence between the index of frequency, as referred to the total strength, and that referred to the amount of waggons loaded. This difference is explained by the influence of the intensity of traffic on the accident indices.

In the geophysical industry, the situation is more complicated. The parties work under different conditions and the law of chance applies approximately and with reservation only when the information deals with a very large number of comparable parties.

B. W. Sorge, in Geophysics of October 1955, after stressing the moral responsibility of management towards the safety conditions in parties working in the field, applies himself to the interpretation of the data concerning 1/3 of the American geophysical industry, or about 200 crews working under relatively similar conditions. He records that for big operators the rate of frequency varies from 85.4 to 0.61. For small operators totalling less than 100,000 hours of work per year, the dispersion is greater: between 175 and 0.

On the more modest scale of the E.A.E.G. any statistics would only have some interest of all thise approached had spontaneously answered the questionnaire sent out on February 16, 1955, by the President of the Safety Committee and had regularly pooled their statistical information. It is probable that the European geophysical activity would have been large enough to initiate investigations of the kind made by B. W. Sorge. Unfortunately a large number of the operators were reluctant to divulge information apparently considered as confidential.

Consequently, in order to show the importance of statistical analyses we must content ourselves with a brief outline of the paper by B. W. Sorge.

Afterwards we shall make suggestions valid within individual concerns.

American statistics (B. W. Sorge—Geophysics—October 1955)

From 1950 to 1954 only one third of the geophysical organizations took part in a common action. Later, the interest shown by some participants weakened and, instead of the improvement expected for 1954, a set-back was recorded with a reversion to the level of 1952. However, the improvement from 1950 to 1954 has resulted in savings amounting to more than 1.5 million dollars for the whole geophysical industry.

The statistics show that geophysics is one of the hazardous industries, and that the number of accidents caused by vehicles has a tendency to increase. The remoteness of the base of operations seems to explain this fact. Excessive speed is the principal cause of accidents. On the other hand, the rate of accidents incurred by drillers and their helpers has diminished. Hand injuries predominate, followed by sprains and strains and next come accidents to the eyes. The common pipe wrench continues to be the cause of many accidents. Although specially designed equipment has been put into service, pipe wrenches are still largely used despite their dangerous nature.

B. W. Sorge insists on the instruction of new recruits, driller, drivers with special reference to the hazards of lifting operations. Finally, he shows that through improving safety measures, the geophysical industry has realized considerable savings on insurance costs. Through intensive efforts a company which was paying an insurance penalty of 13,000 dollars in 1950 received a refund of 30,200 dollars in 1953.

Statistics within a company

All geophysical operators whatever their size must keep their statistics up to date. Every year, even more often if needed, an assessment must be made while keeping the following precautions:

a) Seek numerical information which might be truly significant. If the concern is large enough, and has several dozens of field parties, it will be easy to sift out the significance of some of the figures.

b) Be mistrustfull of hasty conclusions. For instance, do not lighty compare the accident frequency between two different groups of field parties. Such figures are seldom significant for small outfits.

It is often found, very large organizations excluded, that figures do not allow a truly quantitative interpretation unless periods of several years are considered. But even if precise laws cannot be formulated precious clues can be collected by the combined study of statistical summaries on the one hand, and accident reports on the other. In other words, the most characteristic accident reports must be compared with each other to bring out the recurrent or similar factors. The situation can often be clarified by presenting the facts in the form of a summarized table. Without being able to put forward definite percent rates it might be established that certain categories of prospectors are much more liable to accident than others and that accident frequency tends to increase in certain types of topographic, climatic conditions, etc.

Here is a typical example of the "human factors" in relation to accidents occuring to drillers during a 3 months' period in a group of several field parties.

Human factor	*Service*	*Age*
Ignorance of danger	3 months	23 years
Inattention	2 ,,	17 ,,
,,	5 years	29 ,,
Fatigue	10 ,, ,,	39 ,,
Unsuitable foot-wear	2 ,,	28 ,,
Inattention	1 ,,	20 ,,
Fatigue	5 ,,	47 ,,
Lack of skill	4 ,,	27 ,,
,, ,, ,,	2 ,,	25 ,,

This summary inspires the thought that efforts should be made towards the "psychological" education of the young and the testing of the degree of physical resistance of the aged. Summaries of the same kind can be made for the analysis of different technical causes.

It is desirable that the various geophysical organizations should pool the comments drawn from their accident reports and charts. Until statistics are built up adequately these elements would constitute an interesting primary documentation.

CONCLUSIONS

The present situation appears to be that the compilation of general accident statistics still affers itself as an objective for the Safety Committee of the E.A.E.G., but as yet this remains a very remore objective. It will be utterly impossible to exert a beneficial influence as long as information is not centralized and then widely circulated.

However, if the geophysicists of the E.A.E.G. wish to follow the road of progress, they must forthwith enforce the rules listed below.

All accident reports must be drawn up according to specific standards.

All errors and omissions must be corrected and, when necessary, further explanation must be obtained.

Deductions must be made of the technical causes and the human factors involved.

Summaries, showing the weaknesses of personnel, equipment and methods must be drawn up.

The statistics must be interpreted as far as circumstances permit.

In this way the enquiry into causes an into human factors should lead to a great advancement at all levels.

EINIGE NEUERUNGEN AN DEN GEOMAGNETISCHEN FELDWAAGEN *

VON

G. FANSELAU

ABSTRACT

At the Niemegk Observatory geomagnetic balances with torsion ribbons have been constructed since a few years. They have well known advantages over balances resting on knife edges: greater stability of the zero position, ease of enlarging the measuring range by torsion, no serious damage when the instrument is not clamped. Both H- and Z- balances have proved highly satisfactory. Also a combined H- and Z- balance has been developed. To a certain extent, the torsion ribbon balances can be made insensitive to levelling errors. Torsion wire balances used as zero instruments have not been considered for field measurements for reasons of time saving. They are however being made for laboratory measurements.

Am Adolf-Schmidt-Observatorium für Erdmagnetismus in Niemegk wurde vor etwa 8 Jahren mit Versuchen begonnen, die Schneidenlagerung bei den Geomagnetischen Feldwaagen durch eine Bandaufhängung zu ersetzen. An sich ist dieser Gedanke sehr naheliegend und auch nicht neu; solche Versuche wurden bereits von Angenheister (1926), Königsberger (1925) und skandinavischen Geophysikern unternommen. Es wurde zunächst Wert darauf gelegt, ein möglichst robustes Gerät zu konstruieren, das sich von den üblichen Schneidenwaagen sowohl in der äusseren Form als auch in der Handhabung nicht wesentlich unterscheiden sollte, das aber auf Grund der verwendeten Bandaufhängung des Magnetsystems eine ganze Reihe typischer Vorzüge gegenüber den Feldwaagen mit Schneidenlagerung aufweist. Diese Vorzüge liegen auf der Hand; im wesentlichen sind zu nennen: Erhöhung der Stabilität des Basisstandes des Gerätes, bequeme Erweiterung des Messbereiches durch Veränderung der Bandtorsion und schliesslich keine ernstlichen Schäden am Gerät bei Nichtarretierung. Im Laufe der Zeit wurden mehrere hundert solcher Waagen gebaut und eingesetzt, die sich gut bewährten sowohl zur Messung der Vertikalintensität als auch der Horizontalintensität. Das Äussere einer solchen Waage unterscheidet, sich wie gesagt, nicht wesentlich von dem des üblichen schneidengelagerten Instruments. Zusätzlich ist lediglich ein Torsionsknopf mit Skala vorgesehen, um die Bandtorsion messbar zu verändern (Abb. 1, rechts). Über diese einfachen Waagen ist an sich nicht viel zu sagen. Mann kann alles

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* Presented at the Tenth Meeting of the European Association of Exploration Geophysicists, held in Hamburg, 16/18 May 1956. Mitteilung aus dem Geomagnetischen Institut und Observatorium Potsdam-Niemegk Nr. 55.

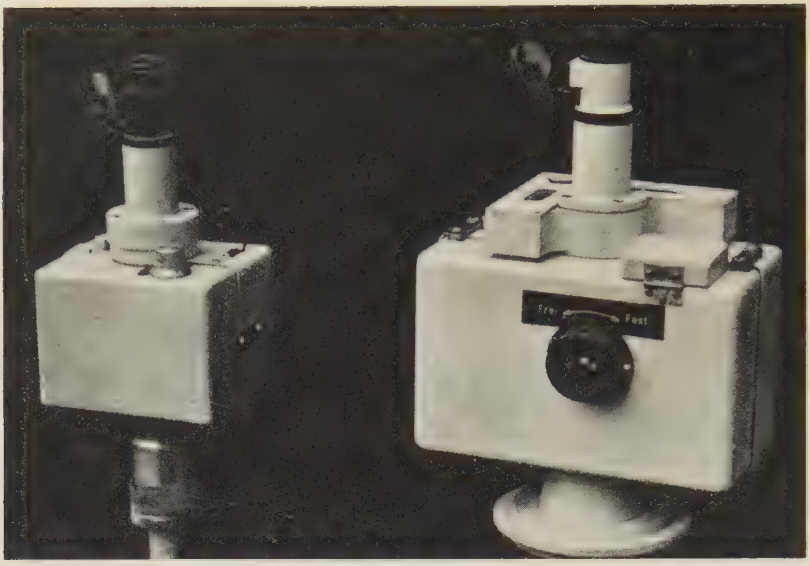

Abb. 1. Normale Fadenwaage (rechts) und geomagnetische Kleinwaage mit Bandaufhängung (links).

Magnetometer with torsion band suspension; normal size (right) and small model (left).

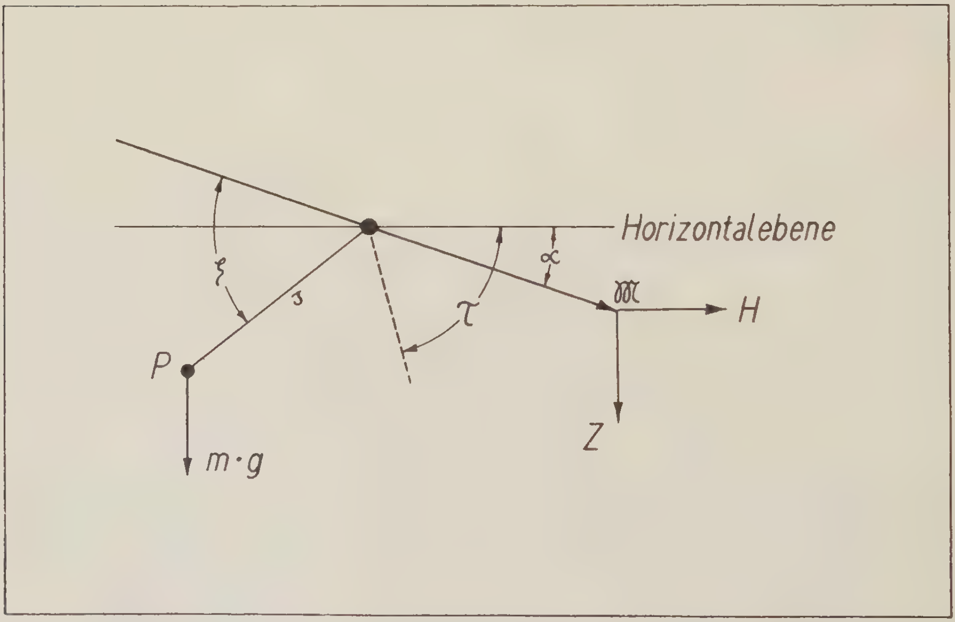

Abb. 2. Zur Ableitung der Gleichgewichtsbedingung einer Geomagnetischen Feldwaage.
Illustrating the derivation of the equilibrium condition of a magnetic balance.

Wesentliche hierüber in den bereits vorliegenden Veröffentlichungen nachlesen (Fanselau, 1948, 1949, 1951). Es sei hier nur darauf hingewiesen, dass sich solche Geräte wesentlich besser und genauer justieren lassen als dies bei den Schneidenwaagen der Fall ist, und dass sie auch bei erhöhter Empfindlichkeit stabil bleiben. Zunächst wurde bewusst davon Abstand genommen, das Gerät als Nullinstrument auszubilden, d.h. also die Torsion des Aufhängebandes als Messnormale zu verwenden, obwohl ich schon gelegentlich auf diese an sich naheliegende Möglichkeit hingewiesen habe. (Fanselau 1953a). Aber auch ohne Anwendung dieser Nullmethode sind mit diesen Bandwaagen Vergleichsmessungen zwischen weit entfernten Observatorien mit äusserst befriedigenden Ergebnissen durchgeführt worden, die durchaus in der zu erwartenden Fehlergrenze lagen. Diese Fehlergrenze wird ja nur gegeben durch die Genauigkeit des Skalenwertes, der auf etwa 2-3‰ bekannt ist.

Die Bandaufhängung bietet aber darüber hinaus noch die Möglichkeit, die Feldwaage wesentlich zu vervollkommnen und zwar in der Richtung einer kombinierten Waage, die es gestattet, direkt hintereinander sowohl Z als auch H zu messen. Man kann das leicht auf folgende Weise einsehen. Die vereinfachte Grundgleichung der magnetischen Fadenwaage lautet:

$$\cos\alpha\,(MZ - mg\,C) - \sin\alpha\,(MH + mg\,S) + D\,(\tau - \alpha) = 0 \tag{1}$$

Dabei bedeutet M das Moment des Magneten, m die Masse des gesamten Magnetsystems, g die Schwerebeschleunigung, s den Abstand des Systemschwerpunktes vom Drehpunkt, H die Horizontalintensität, Z die Vertikalintensität, τ den Winkel der Vorspannung der Torsion, α die Neigung des Magneten unter die Horizontale und D die Torsionskonstante des Aufhängebandes; ferner wurde gesetzt $C = s\cos\zeta$, $S = s\sin\zeta$ (Abb. 2).

Erreicht man durch eine besondere Abstimmung des Gerätes, dass das magnetische Drehmoment und das Drehmoment der Erdschwere sich gerade kompensieren, so bedeutet das nach (1), dass für $\tau = 0$ folgende Bedingungen erfüllt sind:

$$MZ - mg\,C = 0 \text{ und } MH + mg\,S = 0 \tag{2}$$

Naturgemäss lässt sich eine solche Abstimmung nur durchführen für ein vorgegebenes Wertepaar H_0, Z_0, ebenso wie ja auch eine einfache Z- und H-Waage nur für einen vorgegebenen Wert der zu messenden Komponente genau in ihrer Soll-Lage horizontal und vertikal einspielt. Eine Fadenwaage, die in der obenbeschriebenen Weise abgestimmt ist, verhält sich so, als ob das Magnetsystem im Schwerpunkt, d.h. also indifferent, aufgehängt wäre, und als ob der Magnet das Moment Null hätte. Von den drei wirksamen Drehmomenten: Erdmagnetismus, Schwerebeschleunigung und Bandtorsion bleibt also nur noch das letzte übrig, und man erkennt sofort, dass der Magnet der Veränderung der Bandtorsion folgt. Man kann also erreichen, dass beim Kippen des Gerätes um die Bandlängsachse — ein Vorgang, der gleichbedeutend ist mit einer Torsion des Bandes — der Magnet dieser Kippung folgt. Kippt man speziell um 90°, so wird ein Magnet, der vorher z.B. horizontal stand, sich jtzte senkrecht einstellen und umgekehrt. Man kann also in dieser sehr einfachen Weise in kürzester Zeit aus einer *H*- eine *Z*-Waage machen und umgekehrt. Die Indikationen bei lokaler oder zeitlicher Änderung der zu messenden Komponenten des Erdfeldes werden genau so wie bei der einfachen *H*- oder *Z*-Waage direkt an der Okularskala des Fernrohres abgelesen. Das Gerät ist nämlich so konstruiert, dass das Kippen an einem drehbaren Einsatz im Inneren der Waage vorgenommen wird, wobei das Magnetsystem jetzt zwei genau um 90° versetzte Spiegel trägt. Je nach der Stellung der Bandtorsion kann einer der beiden Spiegel an der Okularskala des Fernrohres abgelesen werden. Die Anschläge, bis zu denen der Einsatz im Inneren der Waage gedreht werden kann, sind verstellbar, und diese Verstellung kann ja — ähnlich wie die Bandtorsion bei den einfachen Waagen — an einem Knopf mittels einer Skala abgelesen werden. Auf diese Weise ist es möglich, die Torsion für die Horizontal- und die Vertikalkomponente getrennt voneinander zu verstellen. Das bedeutet einen grossen Vorteil insofern, als beim Übergang von einer Komponente zur anderen nicht die zuerst eingestellte Torsion wieder vollständig rückgängig gemacht werden muss. Das wäre besonders nachteilig, wenn starke örtliche Gradienten gemessen werden müssen, die zudem noch in beiden Komponenten unabhängig von einander und häufig sogar gegensinnig verlaufen können.

Man kann leicht nachrechnen, dass bei der Vorspannung $\tau = 0$ die Skalenwerte für die Messungen beider Komponenten genau gleich sind. Ist Vorspannung vorhanden, so laufen die Skalenwerte auseinander und zwar umsomehr, je grösser diese Vorspannung ist. Ihr Mittel ergibt aber immer den Skalenwert für Bandtorsion $\tau = 0$.

Über die Temperaturkompensation des Gerätes sei kurz vermerkt, dass für die beiden Komponenten getrennt kompensiert wurde, für *Z* in der allgemein üblichen Weise, wie sie auch bei Schneidenwaagen zur Anwendung kommt, bei *H* mit Hilfe von Thermoflux. Abb. 3 zeigt die Güte der erreichten Kompensation.

Da bei dem Gerät die Aufhängung des Magnetsystems mit Hilfe der gleichen Bänder vorgenommen wurde wie bei den einfachen *H*- oder *Z*-Waagen, konnte nicht vermieden werden, dass das Band beim Kippen um seine Längsachse in elastisch verschieden wirksame Stellungen relativ zur Schwerebeschleunigung kam, flachkant oder hochkant. Dieser störende Umstand wurde dadurch beseitigt, dass das Band in den beiden Messlagen unter 45° geneigt verwendet wurde (Abb. 4). Das Durchhängen ist damit für diese beiden Messlagen das gleiche. Bei Verwendung von runden Drähten statt Bändern wäre diese Vorsichtsmassnahme nicht erforderlich gewesen, und man hätte zudem jede beliebige Lage des Magneten zur Messung verwenden, d.h. also prinzipiell jede Komponente messen können. Aus Gründen einer absolut

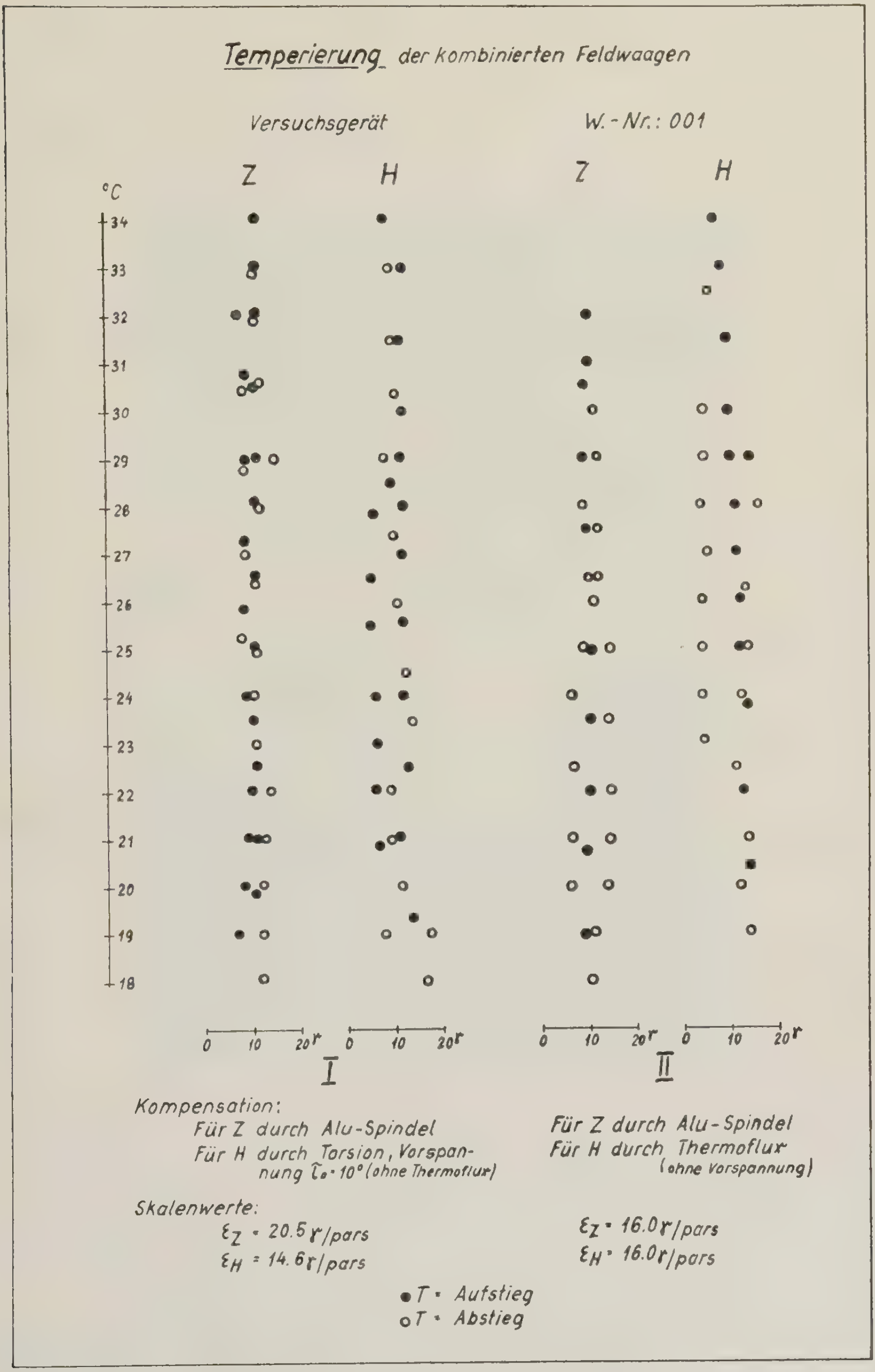

Abb. 3. Temperaturkompensation der kombinierten Fadenwaage.
Temperature compensation of the combined torsion magnetometer.

einwandfreien Klemmung wurde jedoch bewusst auf die Verwendung von Drähten, selbst solcher mit bandförmig ausgewalzten Enden, verzichtet. Die Messung von *H* und *Z* ist ja auch in der überwiegenden Mehrzahl der Fälle das wichtigste Problem. Es sei noch darauf hingewiesen, dass der obenbeschriebene Kippvorgang um 90° naturgemäss so zu verstehen ist, dass dabei der Magnet in Richtung des magnetischen Meridians liegt, in der Lage also, die für die Messung der Horizontalintensität erforderlich ist. Dann wird also auch die Vertikalkomponente bei der Stellung des Magneten in der Ebene des magnetischen Meridians gemessen und nicht wie üblich in der hierzu senkrechten Ebene. An sich bietet das keinerlei prinzipielle Nachteile, erfordert lediglich das Anbringen einer kleinen Korrektur, wie sie ja bei der *H*-Waage sowieso notwendig ist (Fanselau, 1956). Es handelt sich in beiden Fällen darum, den Einfluss der jeweils störenden Komponente zu eliminieren, bei der Horizontalintensität *Z*, bei der Vertikalintensität *H*.

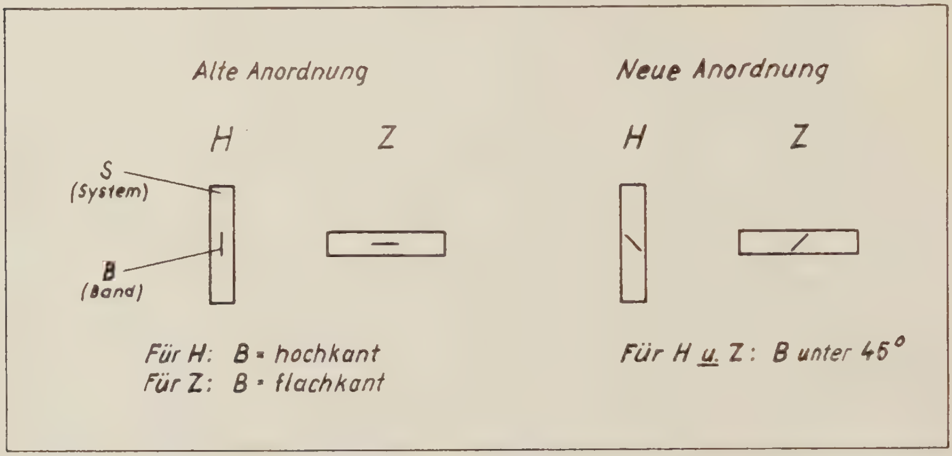

Abb. 4. Bandlage bei der kombinierten Fadenwaage.
Illustrating the position of the torsion band in the combined torsion magnetometer; old arrangement (left) and new arrangement (right).

Das Äussere des Gerätes unterscheidet sich nicht wesentlich von dem der einfachen Waagen (Abb. 5). Die Abmessungen sind naturgemäss ein wenig grösser, und statt eines mit einer Teilung versehenen Knopfes — Bandtorsion — bei der einfachen Waage sind hier deren zwei vorgesehen, einer für *H* und einer für *Z*. Will man die Vertikalintensität nicht bei der Magnetstellung im magnetischen Meridian messen, so hindert nichts, das Gerät beim Übergang von der Messung der Horizontalintensität zur Messung der Vertikalintensität nicht nur um die Bandlängsachse um 90° zu kippen, sondern danach um die Vertikale um 90° zu drehen. Beide Vorgänge lassen sich in einer halben Sekunde durchführen. Der Skalenwert ist in diesem Fall für *H* und *Z* nicht mehr gleich, sondern das Gerät ist für *Z* entsprechend empfindlicher, in den mittleren Breiten Europas etwa um 5 γ im Skalenwert. Die Empfindlichkeit des Gerätes ist naturgemäss durch die oben beschriebene Abstimmung prinzipiell festgelegt und ähnlich wie beim Unifilar gegeben durch das Verhältnis von Direktionskraft des Bandes D zum magnetischen Moment des Magneten M. Bei den verwendeten Materialien liegt der Skalenwert in der Grösse von etwa 14 bis 16 γ. Das Gerät ist bereits in mehreren Exemplaren eingesetzt.

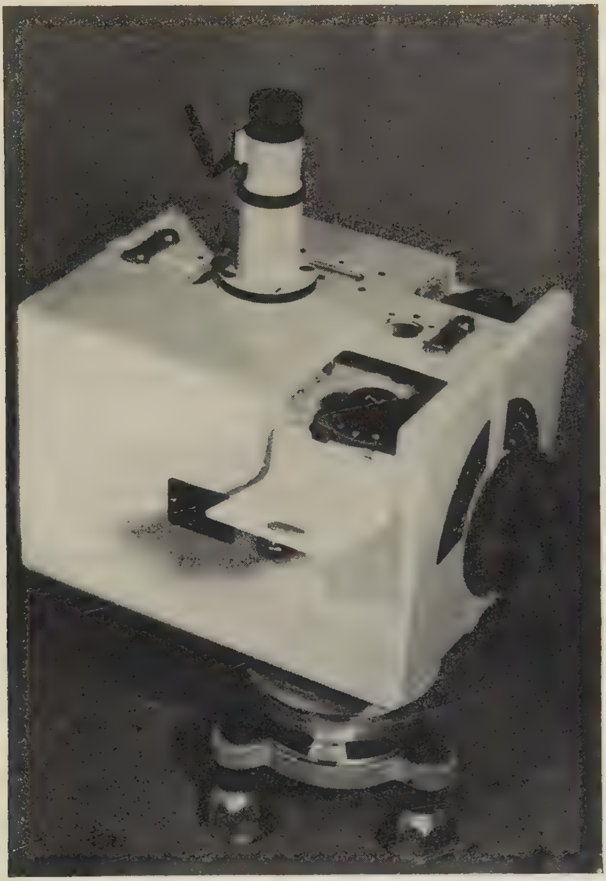

Abb. 5 Kombinierte Fadenwaage.
Combined torsion magnetometer

Ein weiterer grosser Vorteil der kombinierten Feldwaage in der obenbeschriebenen Abstimmung ist die Neigungsunempfindlichkeit. Wie eben kurz erläutert, folgt der Magnet bei der kombinierten Waage auf Grund der besonderen Abstimmung vollständig der Bandtorsion. Dies hat zur Folge, dass der Magnet bei Neigungen des Gerätes um die Längsachse des Aufhängebandes in der Okularskala des Ablesefernrohres stehenbleibt, dass also eine Neigungsempfindlichkeit für die Libelle senkrecht zur Bandlängsachse nicht besteht. Wird ausserdem das Magnetsystem bei den Messungen in der Lage im magnetischen Meridian benutzt, so ist auch eine Neigungsempfindlichkeit für die Libelle parallel der Bandlängsachse nicht vorhanden, d.h. also mit anderen Worten: das Gerät ist völlig neigungsunempfindlich. Wohlgemerkt ist diese Neigungsunempfindlichkeit nicht so zu verstehen, als ob das Gerät überhaupt in jeder beliebigen Lage verwendet werden könnte. Das wäre physikalisch gesehen sinnlos. Vielmehr handelt es sich nur darum, jene Neigungsempfindlichkeit auszuschalten, die dadurch entsteht, dass die Okularskala im Raume sich anders bewegt als der Magnet. Es bleibt dann immer noch jene wahre Neigungsempfindlichkeit des Gerätes übrig, die in der Natur des Messvorganges begründet ist, und die in einer Neigung der Magnetachse um den Winkel ε gegen die Sollage senkrecht zu der zu messenden Feldkomponente besteht. Es wird dann also z.B. nicht H oder Z gemessen, sonder $H \, . \cos \varepsilon$ bezw. $Z \, . \cos \varepsilon$. Man rechnet leicht nach, dass jetzt ein Nivellement auf höchstens $^1/_2{}^\circ$ vollständig ausreicht, in den meisten Fällen jedoch mit einer noch geringeren Genauigkeit im Nivellieren ausgekommen werden kann. Das bedeutet einen grossen Vorteil und zwar in doppelter Hinsicht: Einmal wird durch diese wesentlich geringeren Anforderungen an das Nivellieren ein Arbeitsgang gespart, der besonders bei Messungen im Felde, wo es auf Schnelligkeit ankommt, zu einer beträchtlichen Zeitersparnis führt; dann aber wird durch eine solche Neigungsunempfindlichkeit der Feldwaage auch deren Genauigkeit wesentlich gesteigert, denn es ist eine bekannte Tatsache, dass durch ungenaues Nivellieren wesentliche Fehler bei den Ablesungen der Feldwaage gemacht werden können, besonders dann, wenn die Libellen durch Strahlungswetter thermisch beeinflusst werden und durch Weglaufen die Sicherheit des Nivellements erheblich gefährden.

Es lag daher der Gedanke nahe, diese Neigungsunempfindlichkeit, wie sie bei der besonderen Abstimmung der kombinierten Waagen vorliegt, auch bei den einfachen H- und Z-Waagen auszunutzen. Es lässt sich dies ohne weiteres erreichen, wenn man auch diese Geräte prinzipiell genau so abstimmt, wie dies bei der kombinierten Waage der Fall ist, sie aber trotzdem nur als einfache H- oder als einfache Z-Waage verwendet. Selbstverständlich ist damit eine gewisse Einbusse an Genauigkeit verbunden, wie oben schon erwähnt wurde. Der Skalenwert steigt bei den gegenwärtig benutzten Materialien von 10 γ auf 16 γ. Dessenungeachtet treten aber dann alle erwähnten Vorteile in Erscheinung, und es hat sich gezeigt, dass bei ungünstigem Strahlungswetter mit diesen Geräten neben einer wesentlichen Verkürzung der Messzeit auch eine Steigerung der Genauigkeit erzielt werden konnte, obwohl der Skalenwert jetzt etwas grösser, das Gerät also etwas unempfindlicher ist. Bei den H-Waagen, die so abgestimmt sind und bei denen ja zwangsweise die

Messung mit der Magnetlage im magnetischen Meridian durchgeführt werden muss, ist damit eine vollständige Neigungsunempfindlichkeit des Gerätes erzielt, bei den Z-Waagen naturgemäss nur dann, wenn auch hier mit dem Magneten im magnetischen Meridian gemessen wird. Will man Z in der Magnetlage senkrecht zum magnetischen Meridian messen, so kann man auf alle Fälle durch die eben beschriebene Abstimmung des Gerätes erreichen, dass die Neigungsempfindlichkeit wenigstens in Bezug auf eine Libelle fortfällt, nämlich die senkrecht zum Bande (Fanselau, 1953 b). Es bleibt dann nur noch die Neigungsempfindlichkeit für die Libelle parallel zum Band bestehen. Im Ganzen gesehen bedeutet das natürlich ebenfalls schon eine wesentliche Erleichterung.

Die Möglichkeit, exakte Messungen der geomagnetischen Feldkomponenten durchzuführen, ohne genötigt zu sein, das Gerät sehr genau zu nivellieren, liess den Wunsch aufkommen, ein kleines, äusserst handliches, für schnelle Übersichtmessungen geeignetes Feldmessgerät zu entwickeln, wie es seitens der Geologen häufig benötigt wird. Eine solche kleine Feldwaage wurde im Geomagnetischen Observatorium in Niemegk konstruiert und hat sich im Einsatz gut bewährt. Die äussere Ansicht des Gerätes und einen Vergleich mit den Dimensionen einer normalen Feldwaage zeigt Abb. 1. Dieses Gerät ist ebenso abgestimmt und temperaturkompensiert wie es oben bei der kombinierten Waage beschrieben wurde. Es ist zunächst als Vertikal-Feldwaage ausgebildet, aber auch ohne weiteres als Horizontal-Feldwaage möglich, wenngleich hier seitens der Geologen nicht das gleiche Bedürfnis vorliegt. Die Waage ist lediglich mit einer Dosenlibelle ausgerüstet, die ungefähr eine Genauigkeit im Nivellieren von 5 Minuten gestattet. Die Waage selbst ist mit einem leichten Stativ fest verbunden und sitzt auf einem Kugelgelenk, mit dessen Hilfe sie durch einfaches Drehen rasch und leicht nivelliert werden kann. Ein Ausrichten des Gerätes nach dem magnetischen Meridian mit Hilfe einer Bussole ist nicht vorgesehen, vielmehr genügt es, bei dem Profilabschreiten im Gelände mit Hilfe eines Marschkompasses ungefähr die Richtung magnetisch Nord festzulegen, um dann die Waage in dieser Richtung einzusetzen. Um dass Gerät unempfindlicher zu machen als es bei den üblichen Bandwaagen der Fall ist, wurde ein etwas stärkeres Band benutzt. Bei der Abstimmung für Neigungsunempfindlichkeit hat das Gerät gegenwärtig einen Skalenwert von 65 γ pro Okularskalenpars. Eine Ablesung der Temperatur ist nicht erforderlich, weil das Gerät gut temperaturkompensiert ist und die verringerte Empfindlichkeit des Gerätes den noch restlichen Temperatureinfluss nicht wirksam werden lässt. Das Gerät war zuerst ohne Arretierung vorgesehen. Gegenwärtig laufen Versuche, eine einfache Arretierung anzubringen, die lediglich durch Drücken eines Knopfes das Magnetsystem freigibt, und nach Ablesung durch Loslassen des Knopfes zwangsläufig wieder arretiert. Die Dämpfung des Gerätes ist äusserst günstig, so dass eine Messung im

Gelände durchschnittlich in 10 Sekunden erledigt ist. Die Waage verbleibt bei Transport auf dem Stativ und kann bei ihrem geringen Gewicht bequem transportiert werden.

Wie oben schon kurz erwähnt, bestand zunächst die Absicht, durch die Konstruktion einer Feldwaage mit Bandaufhängung dem Geologen und praktischen Geophysiker ein Gerät in die Hand zu geben, mit dessen Hilfe er schneller und genauer zu arbeiten in der Lage ist. Aufgrund der Erfahrungen, die vielfältig mit solchen Geräten gewonnen wurden, konnte jetzt dem zunächst zurückgestellten Problem wieder Aufmerksamkeit gewidmet werden, nämlich der Verwendung der Bandwaage als Torsions-Null-Instrument. Es wurde ja bereits oben kurz darauf hingewiesen, dass bei Überwindung grosser Felddifferenzen die Genauigkeit eines solchen Gerätes zwangsweise beschränkt wird durch die Genauigkeit des Skalenwertes, ganz ähnlich wie das bei Gravimetern auch der Fall ist. Wenn man hier weiterkommen will, muss man also eine andere Methode anwenden, eben die Null-Methode. Es liegt auf der Hand, dass die Durchführung dieser Methode etwas mehr Zeit erfordert als das einfache Ablesen des Gerätes im Fernrohr, weil ja ein zusätzlicher Messgang, nämlich die Verstellung der Torsionsspindel bis zur Erreichung der Null-Lage, erforderlich ist. Für Feldmessungen wird man also vielleicht diese Null-Methode im allgemeinen nicht zur Anwendung bringen, da es sich hier nicht um die genaue Erfassung grosser Felddifferenzen handelt, sondern vielmehr darum, in möglichst kurzer Zeit geologisch interessante Profile zu vermessen, wobei bei grossen Indikationen im allgemeinen auch eine geringere Genauigkeit sachlich ohne weiteres in Kauf genommen werden kann. Es ist an sich keine schwierige Aufgabe, die im Vorhergehenden beschriebenen Bandwaagen als Torsions-Null-Geräte auszubilden, es ist lediglich nötig, statt des Torsionsknopfes bei den einfachen H- oder Z-Waagen jetzt zur genauen Bestimmung der Bandtorsion an der Waage einen Teilkreis anzubringen, der etwa mit einer Genauigkeit von $^1/_{10}$ Minuten abgelesen werden kann. Solche Teilkreise, versehen mit einer entsprechenden Verstellmöglichkeit, sind also das einzige Merkmal, durch das sich eine Feldwaage als Null-Gerät von der üblichen unterscheidet. Alles andere bleibt unverändert, wie z.B. die Empfindlichkeit des Gerätes, Temperaturkompensation u.ä. Selbstverständlich wird man auch bei diesen Geräten die Abstimmung der kombinierten Waage vornehmen und jetzt durch Verwendung des Magneten im magnetischen Meridian das Gerät völlig neigungsunempfindlich machen in dem obenangegebenen Sinn. Durch die Rückführung des Magneten mit Hilfe der Bandtorsion in seine Sollage, wie es ja das Messprinzip eines Torsions-Null-Gerätes mit sich bringt, wird ja ganz automatisch der Einfluss der Störkomponente beseitigt, so dass jetzt keinerlei Bedenken mehr bestehen können, auch die Z-Komponente mit dem Magneten im magnetischen Meridian zu messen. Das bedeutet für Messgeschwindigkeit und -Genauigkeit einen grossen Vorteil.

Auch die kombinierte Waage lässt sich ohne Schwierigkeiten in ein solches Null-Gerät umwandeln. Hier wird nicht die Torsionseinstellung des Aufhängebandes an dem Teilkreis abgelesen, sondern die Drehung des Gehäuses im Inneren der Waage. Die oben erwähnten Anschläge bei der kombinierten Waage kommen dann in Fortfall; man liest die Drehung um 90° jetzt direkt am Teilkreis ab. Versuche mit solchen Torsions-Null-Geräten sind gegenwärtig im Gang. Eines jedoch kann jetzt schon mit voller Sicherheit gesagt werden, nämlich, dass die Genauigkeit dieser Geräte die der üblichen Feldwaagen wesentlich — um das Doppelte bis Dreifache — übertrifft. Ferner hat sich gezeigt, dass die Bedenken, eine solche Torsions-Null-Waage für den Feldgebrauch einzusetzen, nicht mehr in vollem Umfange berechtigt sind. Ein solches Torsions-Null-Gerät braucht nämlich auch bei den Messungen der Vertikalintensität nicht mehr durchgeschlagen zu werden, und dies hat zur Folge, dass die Messungen eine wesentliche Beschleunigung erfahren. Da das Gerät, wie oben bereits erwähnt, neigungsunempfindlich ist und auch dadurch eine Beschleunigung des Messvorganges erzielt wird, hat sich bei den Messungen im Gelände gezeigt, dass die für jede Messstation aufzuwendende Zeit nicht nur nicht grösser, sondern im Gegenteil sogar etwas geringer ist als die Messzeit mit den gewöhnlichen Feldwaagen. Man wird also wohl auch diese Torsions-Null-Waagen mit bestem Erfolg bei den praktischen Arbeiten im Gelände einsetzen. Über weitere Erfahrungen mit diesen Geräten wird in Kürze an anderer Stelle berichtet werden.

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CORRELATION OF ROCK DENSITY DETERMINATIONS FOR GRAVITY SURVEY INTERPRETATION *

BY

J. T. WHETTON**, J. O. MYERS** and R. SMITH**

ABSTRACT

The results of field and laboratory methods of density determination on a series of Coal Measure, Permian and Triassic rooks are presented and the different methods compared. It is concluded that the most satisfactory method is that of measuring the vertical change of gravity in a mine shaft. Nettleton's method is unsatisfactory to us, due to weathering of the rocks (particularly Magnesian Limestone) and possible effects from drift. Laboratory measurements are of variable value depending on the lithology and source of the samples.

A method adopted to solve the problem of finding the true densities for use in a local gravity survey in N.E. England is given.

INTRODUCTION

For the reliable interpretation of a gravity anomaly map it is necessary to know as accurately as possible the density of the rocks beneath the surveyed area in order to establish the horizons of maximum density contrast. As gravimeters have improved in accuracy and surveys have become more localised in extent the need for such knowledge has increased and this important aspect of gravity surveying is now being studied in greater detail. In a localised survey made over a portion of the concealed coalfield of Yorkshire (North Eastern Division N.C.B. England) it was necessary to utilise several methods of rock density determination in order to assess the density changes in the range of strata encountered. The different methods have, where convenient, been made to overlap and a correlation between them is thus possible and yields interesting results. Work on such correlations has been published by Hammer (1950) and Parasnis (1952) but their results differ to some extent. This further contribution to the solution of the problems should be of some interest.

REGIONAL GEOLOGY

The reason for the number of methods used in density determinations is partly due to the number of possible horizons of density contrast in the surveyed area. The geology is indicated in Figure 1. The productive Coal Measures of the East Pennine Coalfield of Great Britain outcrop to the east and south

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*) Presented at the Eleventh Meeting of the European Association of Exploration Geophysicists, held in Milan, 12-14 December 1956.

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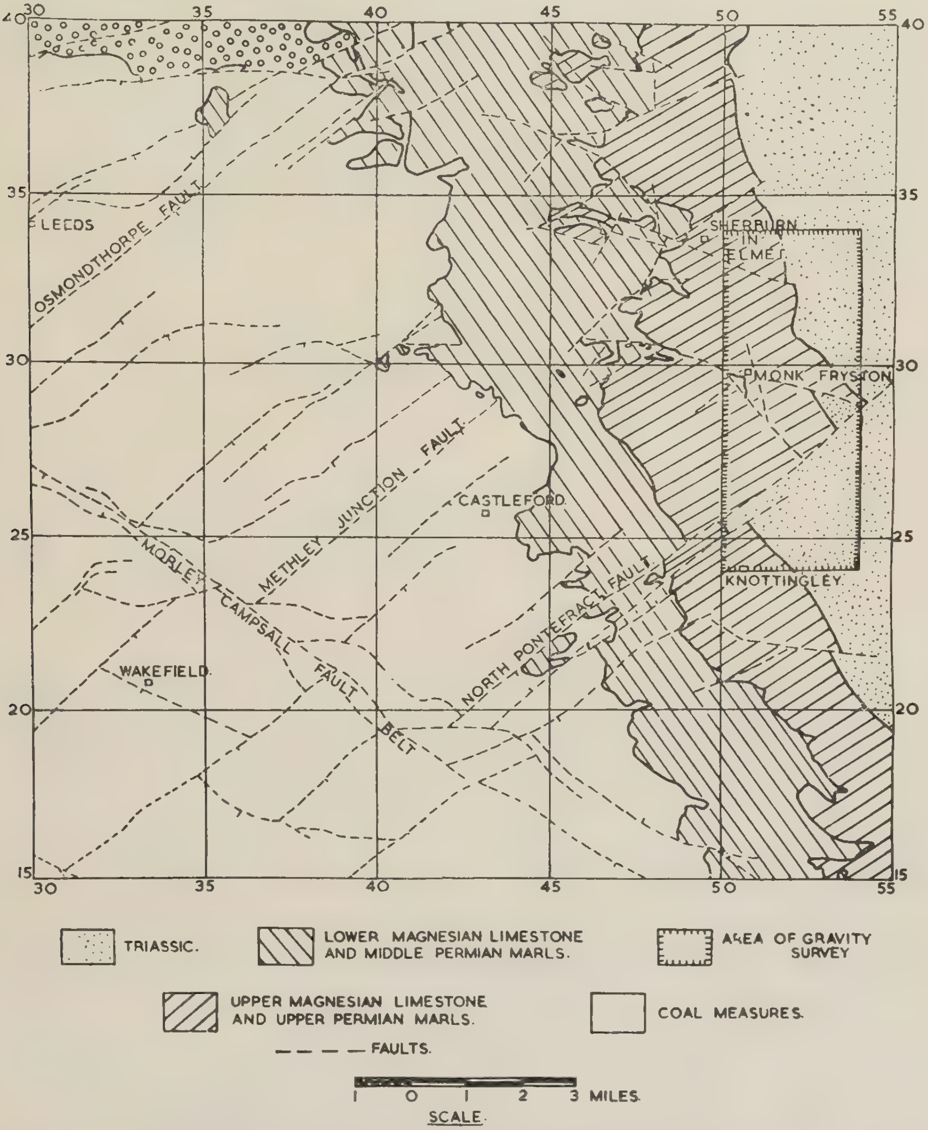


Fig. 1. Regional geology of and around the area of the gravity survey, based on the one-inch maps of the Geological Survey of Great Britain and published with the permission of the Director.

of Leeds and are bounded in the north by the older Millstone Grit series. These two Carboniferous formations, disappear to the east beneath the Permian unconformity. The Permian beds, a series of dolomitic limestones and marls dip gently to the east and are succeeded conformably by Triassic sandstones. The outcrop line of the base of these sandstones can only be conjectured in this region, as it is covered by the extensive drift deposits of the Vale of York. This drift presents difficulties and available information on the solid geology, particularly that of the Coal Measures, has been derived almost wholly from boreholes. To try and establish the structural condition of the Coal Measures over the area indicated (Fig. 1) the gravity survey was initiated.

The succession of rocks in the area of the survey to a depth of some 3000 ft. is shown in Figure 2. It was expected that contrasts, sufficient in magnitude to give measurable gravity anomalies at the surface, might be present at seven interfaces above the Coal Measures. These were—

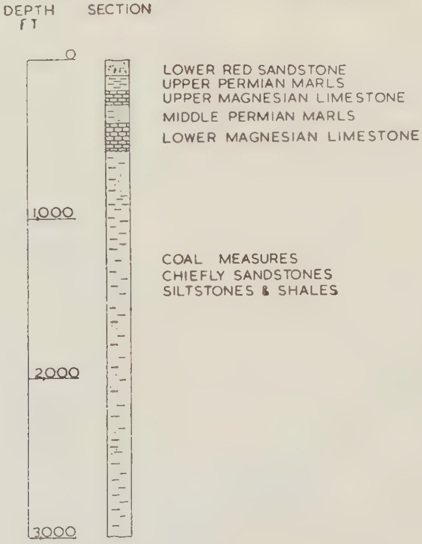


Fig. 2. Succession beneath the survey area.

(1) Drift — Lower Red Sandstone
(2) Drift — Upper Permian Marls
(3) Drift — Upper Magnesian Limestone
(4) Lower Red Sandstone — Upper Permian Marls
(5) Upper Permian Marls — Upper Magnesian Limestone
(6) Upper Magnesian Limestone — Middle Permian Marls
(7) Middle Permian Marls — Lower Magnesian Limestone

Hence appreciable gravity anomalies could arise from irregularities in post-Carboniferous beds. An important contrast was also expected at the Permian-Coal Measure plane of unconformity and from our experience an increase of density with depth within the Coal Measures.

Methods Applied and Results

Standard laboratory and field methods have been used and measurements made on the following lithological types.

(1) A poorly cemented ferruginous sandstone; in this case the Bunter sandstone of the English Triassic.
(2) Marl beds often containing gypsum and anhydrite; the Upper and Middle Permian Marls of Yorkshire.
(3) Magnesian Limestone beds both massive and flaggy; the Upper and Lower Magnesian Limestone of the Yorkshire Permian.
(4) A succession of alternating beds of sandstones, siltstones, mudstones and shales in the Coal Measures in which individual beds rarely attain a thickness of more than 40 ft.

For purposes of correlation the methods of density determination are divided into four groups covering laboratory measurements in A and B, and field measurements in C and D.

(A) Rock samples from quarries and coal mines
(B) Rock samples from boreholes
(C) Determinations from hill measurements
(D) Determinations from mine shaft measurements.

Method A

These were made on samples from the Coal Measure and Upper and Lower Magnesian Limestone series of beds, collected from coal mines and quarries. Specimens were, where possible, collected from recently blasted faces where the rock was least weathered but it cannot be contended that they were absolutely fresh.

The method of density determination is similar to that described by Holmes (1921) and consists of saturating the specimen with distilled water in vacuo and then weighing whilst suspended in air and water. The samples were then dried in an oven and weighed to find their dry weight. The results are presented in Table I.

A. Table I.

Strata	Number of Determinations	Average dry density	Average wet density	Range of saturated density
U.M.L.	31	2.32	2.48	2.28-2.68
L.M.L.	17	2.15	2.39	2.23-2.49
C.M.	51	2.47	2.57	2.37-3.16

U.M.L. = Upper Magnesian Limestone
L.M.L. = Lower Magnesian Limestone
C.M. = Coal Measures

B.

No.	Coal Measure sample lithology	Dry density	Wet density
47	Fine Grained Sandstone	2.22	2.40
34	,, ,, ,,	2.24	2.41
37	Siltstone	2.27	2.42
35	Fine Grained Sandstone	2.30	2.44
48	,, ,, ,,	2.33	2.45
28	,, ,, ,,	2.37	2.49
39	Siltstone	2.36	2.49
36	,,	2.39	2.51
26	,,	2.41	2.53
33	Mudstone	2.43	2.53
29	Clay Siltstone	2.44	2.55
42	,, ,,	2.49	2.56
30	Fine Grained Sandstone	2.50	2.58
46	Clay Siltstone	2.47	2.62
44	,, ,,	2.64	2.68
25	Mudstone	2.75	2.76
27	,,	2.79	2.83
40	Clay Ironstone	3.11	3.16

Densities in grms./c.c.

The average results appear to indicate significant contrasts between the beds from which the samples were derived but the wide range recorded in each case calls for careful consideration. Only a small number of the Coal Measure samples have come from different depths in the same colliery. They are too few to give definite indication of change of density with depth. As might be expected a correlation between density and lithology in these samples is indicated. Sandstones are on the whole less dense than siltstones which are in turn of lower density than mudstones (Table I, Part B).

METHOD B

To obtain more satisfactory density data and a comparison of results with those of other methods, particularly method D, measurements were made on a series of borehole samples. The samples were collected from a National Coal Board borehole at Kellington (Figure 3) to the east of the southern part of the survey area. Ninety three core samples were collected from the borehole representing rock types between depths of 315 ft. and 1,900 ft. below Ordnance Datumn i.e. from the point where core-taking commenced through 285 ft. of Permian and 1,300 ft. of Coal Measure beds. The large core samples from the boreholes were (1) drilled and shaped into smaller cores (see Figure 4); (2) broken by a hammer into smaller pieces. Where possible four of each of these were used for the measurements and the procedures adopted were as follows:—

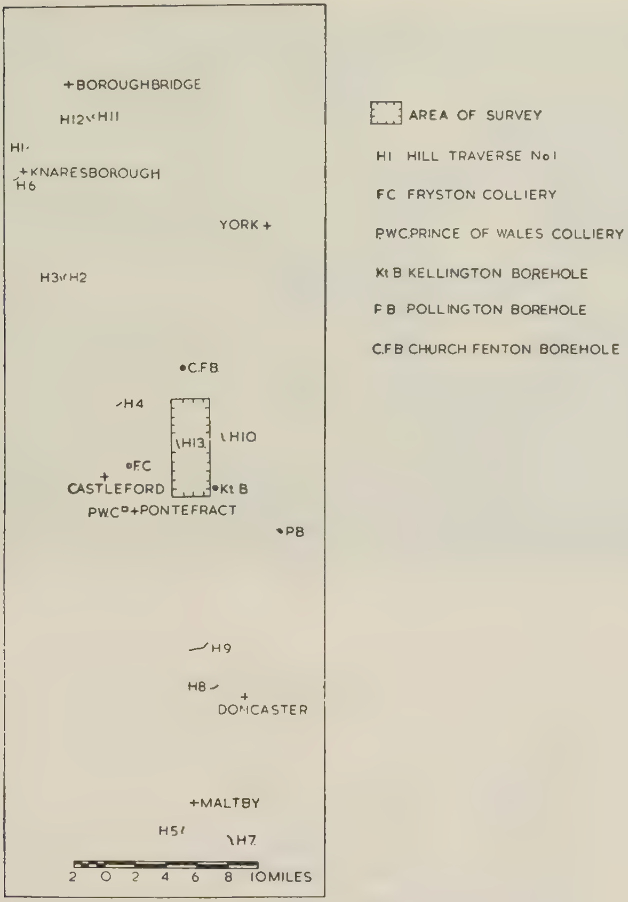


Fig. 3. Location plan of field methods and boreholes.

Cores

(1) Specimens dried in an oven for at least 12 hours.
(2) Weighed dry and then placed in an evacuating flask and saturated with distilled water under vacuum conditions for 2 hours.
(3) Left in distilled water for at least 24 hours.
(4) Weighed suspended in air and water.
(5) Dried in an oven for at least 12 hours.
(6) Weighed dry.
(7) Placed in desiccator for at least 24 hours.
(8) Weighed dry.

If readings (6) and (8) were appreciably different the specimen was again placed in a desiccator for 24 hours and weighed dry.

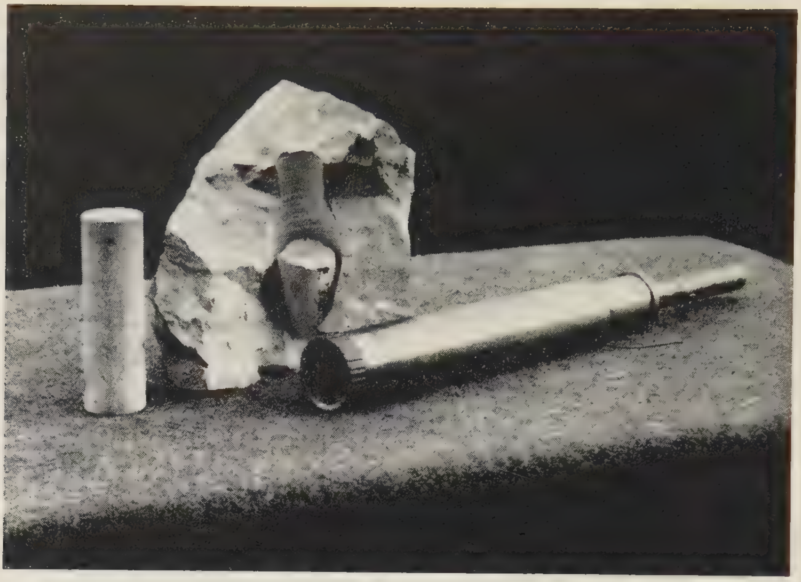


Fig. 4. Typical core specimen. The core barrel is shown and is approx. 8.4 inches long.

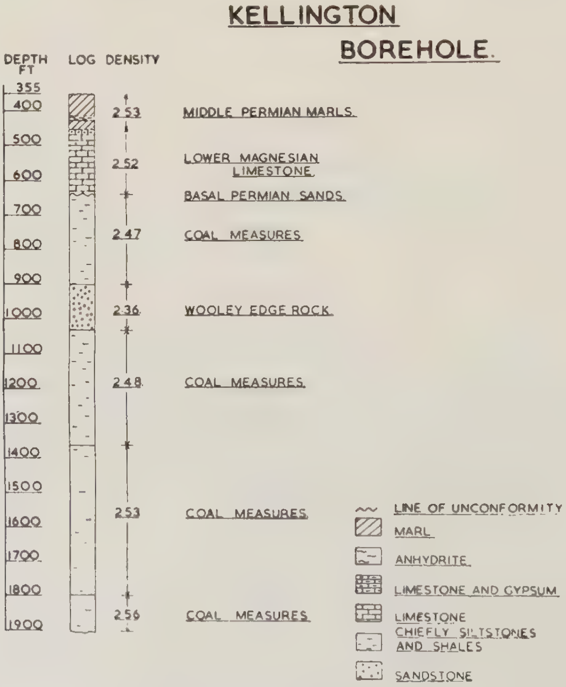


Fig. 5. Results of measurements on samples from Kellington Brehoole.

NON-CORES

(1) Specimens dried in an oven for at least 12 hours.
(2) Weighed dry then gradually covered by distilled water over a period of 2 hours.
(3) Left in distilled water for at least 72 hours.
(4) Weighed suspended in air and water.
(5)-(8) As for cores.

The average results of 350 determinations on such samples are indicated in Figure 5. Some of the results are given in more detail in Table II to illustrate the various points summarised below.

The samples obtained from the Middle Permian Marl series (numbers 2-5 in Table IIA) give an expected wide range of densities due to the different amounts of gypsum and anhydrite in the Marl beds. The Middle Permian Marl succession in the Kellington borehole is:

Red and grey marls with gypsum ...	66 ft.
Anhydrite	17 ft.
Marl and gypsum..................	24 ft.

Samples 2 and 3 came from the upper bed, 4 from the anhydrite band and 5 from the lower bed. By taking the average of the results obtained and weighting them proportionally to their thickness in the borehole the value of 2.53 grams/cc. for the Middle Permian Marls as indicated in figure 5 has been derived. It clearly depends upon the amounts of gypsum and anhydrite present and is therefore not reliable for use over a large area. The value of 2.68 grams/cc. obtained for the Marl specimen 3 is perhaps of more importance.

Samples 7 to 15 represent the Lower Magnesian Limestone series as found in the borehole. Again differences in density due to the presence of varying amounts of gypsum were apparent but the range of saturated densities (2.48-2.64) grams/cc. is much less. The average value of 2.52 grams/cc. given in Figure 5 was derived in a similar manner to that applied for the Middle Permian Marls. The results given for 10 and 12 and to a lesser degree those for 11 (Table II) indicate that the values derived for the core samples are on the whole higher than those found for the non-cores.

Details of measurements on five large samples from Coal Measure horizons are given in Table II Part C and the difference between results from cores and other samples is again apparent. The divisions given in Figure 5 are again derived by weighting the densities proportionally to rock thickness. The Woolley Edge Rock a coarse sandstone of low density forms a major density break and the others indicated i.e. the (2.48-2.52) grams/cc. and the (2.52-2.56) grams/cc. are arbitrarily chosen from inspection of the results. Hence, apart from the anomalous low density of the Woolley Edge Rock an increase of density with depth for the Coal Measures is indicated by the measurements. Such an increase is an important factor in explaining the observed gravity anomalies.

TABLE II

A. MIDDLE PERMIAN MARLS

No.	Dry ρ	Sat ρ	Lithology	Depth (ft.)	C-Core N.C.-Not a Core	Ave. Dry	Ave. Sat.
2a	2.30	2.32	Marl with Gypsum	400	C	2.34	2.35
2b	2.34	2.35	,,	,,	C		
2c	2.32	2.35	,,	,,	C		
2d	2.33	2.35	,,	,,	N.C.		
2e	2.51	2.53	,,	,,	N.C.		
2f	2.30	2.31	,,	,,	N.C.		
2g	2.30	2.31	,,	,,	N.C.		
2h	2.30	2.31	,,	,,	N.C.		
3a	2.58	2.69	Marl	415	C.	2.57	2.68
3b	2.57	2.68	,,	,,	C.		
3c	2.56	2.67	,,	,,	N.C.		
4a	2.90	2.90	Chiefly Anhydrite	425	C.	2.90	2.91
4b	2.91	2.92	,,	,,	C.		
4c	2.92	2.92	,,	,,	C.		
4d	2.92	2.92	,,	,,	C.		
4e	2.89	2.90	,,	,,	N.C.		
4f	2.89	2.90	,,	,,	N.C.		
4g	2.90	2.91	,,	,,	N.C.		
4h	2.89	2.90	,,	,,	N.C.		
5b	2.32	2.35	Marl	440	C.	2.26	2.33
5c	2.31	2.31	Gypsum	,,	C.		
5d	2.18	2.31	Marl	,,	C.		
5e	2.24	2.32	,,	,,	N.C.		
5f	2.13	2.30	,,	,,	N.C.		
5g	2.34	2.32	,,	,,	N.C.		
5h	2.29	2.32	Marl with Gypsum	,,	N.C.		

For a reason which follows, the density values for the Lower Red Sandstone obtained by Method C were considered to be not truly representative of the rock as it is found beneath the area of investigation. An attempt to check this by laboratory measurements was made on cores taken from a water borehole at Pollington (Figure 3). These were 2 ft. in diameter throughout most of the hole and 3 ft. near the top. Samples were taken from the centre of these and it is considered that they were reasonably unweathered. Seventy-nine determinations were made giving an average density of 2.35 grams/cc. with a standard deviation of 0.07 grams/cc. Though the samples came from depths

TABLE II

B. LOWER MAGNESIAN LIMESTONE

No.	ρ Dry	ρ Sat.	Lithology	Depth (ft.)	C-Core N.C.-Not a Core	Ave. Dry	Ave. Sat.
9a	2.59	2.59	Magnesian Limestone with Gypsum	520	C.	2.54	2.55
9b	2.49	2.50		,,	C.		
9c	2.55	2.55	,,	,,	C.		
9d	2.59	2.59	,,	,,	C.		
9e	2.51	2.53	,,	,,	N.C.		
9f	2.51	2.52	,,	,,	N.C.		
9g	2.50	2.52	,,	,,	N.C.		
9h	2.58	2.59	,,	,,	N.C.		
10a	2.51	2.52	,,	540	C.	2.50	2.51
10b	2.53	2.53	,,	,,	C.		
10c	2.55	2.55	,,	,,	C.		
10d	2.55	2.56	,,	,,	C.		
10e	2.44	2.45	,,	,,	N.C.		
10f	2.48	2.49	,,	,,	N.C.		
10g	2.46	2.47	,,	,,	N.C.		
10h	2.51	2.52	,,	,,	N.C.		
11a	2.47	2.47	,,	560	C.	2.46	2.47
11b	2.42	2.43	,,	,,	C.		
11c	2.53	2.53	,,	,,	C.		
11d	2.46	2.47	,,	,,	C.		
11e	2.53	2.54	,,	,,	C.		
11f	2.45	2.46	,,	,,	N.C.		
11g	2.46	2.47	,,	,,	N.C.		
11h	2.45	2.46	,,	,,	N.C.		
11i	2.36	2.39	,,	,,	N.C.		
12a	2.51	2.54	,,	580	C.	2.49	2.53
12b	2.52	2.56	,,	,,	C.		
12c	2.54	2.59	,,	,,	C.		
12d	2.50	2.54	,,	,,	C.		
12e	2.42	2.45	,,	,,	N.C.		
12f	2.49	2.53	,,	,,	N.C.		
12g	2.48	2.52	,,	,,	N.C.		
12h	2.48	2.51	,,	,,	N.C.		

below 130 ft. from the surface, they were found to be very friable, with very little cementation. It was therefore considered that density determinations as described above, applied to dry and saturated samples of this type of rock, were of doubtful value and impracticable as regards the time taken. In view of this the large core samples were broken into smaller pieces, weighed and their volumes obtained by measurement of their displacement of water in a graduated flask. By taking a large number of such determinations it is considered that the result obtained is satisfactory.

Similar measurements to those described for the non-core samples in the

TABLE II

C. COAL MEASURES

No.	ρ Dry	ρ Sat.	Lithology	Depth (ft.)	C-Core N.C.-Not a Core	Ave. Dry	Ave. Sat.
31a	2.39	2.51	Fine grey sandstone, with thin bands of mica and carbonaceous materials	806	C.		
31b	2.39	2.51		,,	C.		
31c	2.39	2.52		,,	C.		
31d	2.41	2.52		,,	C.		
31e	2.41	2.51		,,	N.C.	2.39	2.51
31f	2.38	2.50		,,	N.C.		
31g	2.38	2.50		,,	N.C.		
31h	2.38	2.50		,,	N.C.		
32a	2.43	2.53	Similar to the above samples	822	C.		
32b	2.42	2.53		,,	C.		
32c	2.41	2.52		,,	C.		
32d	2.38	2.50		,,	N.C.		
32e	2.39	2.51		,,	N.C.	2.41	2.53
32f	2.40	2.51		,,	N.C.		
32g	2.46	2.61	Part of Ironstone Nodule	,,	N.C.		
33a	2.43	2.56	Grey Siltstone	826	C.		
33b	2.37	2.50	,,	,,	C.		
33c	2.36	2.50	,,	,,	C.		
33d	2.43	2.56	,,	,,	C.		
33e	2.39	2.53	,,	,,	N.C.	2.39	2.52
33f	2.41	2.54	,,	,,	N.C.		
33g	2.38	2.50	,,	,,	N.C.		
33h	2.38	2.50	,,	,,	N.C.		
66a	2.50	2.58	Grey Siltstone	1604	C.		
66b	2.52	2.59	,,	,,	C.		
66c	2.46	2.55	,,	,,	C.		
66d	2.47	2.56	,,	,,	N.C.	2.47	2.56
66e	2.46	2.55	,,	,,	N.C.		
66f	2.49	2.57	,,	,,	N.C.		
66g	2.40	2.52	,,	,,	N.C.		
68a	2.42	2.51	Fine grained sandstone	1616	C.		
68b	2.42	2.51	,,	,,	C.		
68c	2.44	2.53	,,	,,	C.		
68d	2.39	2.50	,,	,,	C.		
68e	2.46	2.54	,,	,,	N.C.		
68f	2.37	2.47	,,	,,	N.C.	2.41	2.50
68g	2.38	2.47	,,	,,	N.C.		
68h	2.39	2.48	,,	,,	N.C.		

first part of this section were also carried out on four samples of Triassic sandstone from a borehole near Church Fenton (Figure 3). The results were:—average dry density 2.00 grams/cc.; saturated 2.22 grams/cc. The specimens came from a depth of 100 ft. below the surface. Though such a result, from only four samples, could not be taken as reliable by itself it does, as will be shown below, fit in with the other measurements recorded.

Method C

A useful method of obtaining density values of rocks *in situ* was first put forward by Nettleton (1939). It consists of making a series of gravimeter observations at different heights over a marked topographical feature, composed of the representative rocks, in an area undisturbed structurally and where the regional gravity gradient is either insignificant or is accurately known and a correction can be applied. The method as described by Nettleton involves the personal judgment of the computer and the final choice of the correct density value is not always easy. The most satisfactory computational form seems to be that published by Parasnis (1952) and it is his method that has been used in all the cases to be described. It assumes a straight line relationship between gravity anomaly and height. By keeping the density traverse lengths short it is considered that regional variations were negligible and the results reliable.

At first sight this would appear to be the best method available for establishing the density of the Permian and Triassic rocks of the area. Unfortunately non-structural topographic features are not common in the neighbourhood of the survey. Hills as far apart as Boroughbridge in the north (Figure 3) and Maltby to the south have been surveyed and the results are presented in table III. The first five indicate an average density of 2.36 grams/cc. with a large range of 2.23-2.50 grams/cc. for the Lower Magnesian Limestone series. Hill surveys numbers 6, 7 and 8 which are over hills composed of predominantly Middle Permian Marls indicate an average of 2.57 grams/cc. for these beds with again a wide range. Hill survey number 9 indicates that the Upper Magnesian Limestone may be similar in density to the Lower Magnesian Limestone. Hills 10, 11 and 12 give an average of 1.90 grams/cc. for the Lower Red Sandstone. The average change in height across these surveys has been of the order of 100 ft. and they have been of varying gradients. This means that any drift present will have a much greater effect on the results than on those obtained from larger hills. It is considered that differences in thickness of drift deposit on these hills may be an important factor causing the range of values observed.

The highest ground within the survey area is composed of Upper Magnesian Limestone. Though the presence of a fault makes it an unsatisfactory hill for the application of this method interesting results have been achieved. The direction of the traverse is parallel to that of the fault so its effect is considered to be at a minimum. The value of 1.90 grams/cc. obtained for the density is not supported by other hill surveys and its low value cannot be due to a relatively thick cover of drift as no such cover exists. It is considered that it can only be due to very extensive weathering. Movement along the Lumby Fault has probably created many fractures and lines of weakness and numerous

TABLE III

Density Values from Hill Surveys

No.	Hill locality	Altitude change (ft.)	Number of stations	Stratigraphy	Density
1	Farnham. 2 miles N. of F Knaresborough	90.5	9	Lower Magnesian Limestone	2.23 ±0.02
2	Linton near Wetherby. Hill just N. of village	85.3	13	Lower Magnesian Limestone	2.50 ±0.07
3	Linton near Wetherby. Hill ½ mile W. of above hill.	97.1	7	Lower Magnesian Limestone	2.43 ±0.06
4	Micklefield. Hill on E. side of Gr. North Road 5 miles N. of Castleford.	90.5	6	Lower Magnesian Limestone	2.30 ±0.04
5	Brookhouse. 2 miles S. of Maltby. Hill N. of village	128.7	8	Lower Magnesian Limestone	2.36 ±0.04
6	Knaresborough. Hill S. of river on main Harrogate road.	102.3	10	Chiefly Middle Permian Marls	2.57 ±0.06
7	Firbeck. 9 miles S. of Doncaster. Hill S. of Village	112.8	10	Middle Permian Marls and Upper Magnesian Limestone	2.51 ±0.06
8	Cusworth. 2 miles N.N.W. of Doncaster. Hill past Cusworth Hall;	77.3	7	Middle Permian Marls and Upper Magnesian Limestone	2.64 ±0.07
9	Woodlands. 4 miles N. of Doncaster. Hill crosses The Gr. North Road	133.7	9	Upper Magnesian Limestone	2.35 ±0.05
10	Hambledon. 3 miles E. of Monk Fryston. Hill S. of village.	114.0	9	Lower Red Sandstone	1.80 ±0.05
11	Grafton. 3 miles S.E. of Boroughbridge. Hill N.E. of village.	121.2	11	Lower Red Sandstone	2.07 ±0.03
12	Marton. ½ mile S. of Grafton. Hill N. of village	102.6	8	Lower Red Sandstone	1.84 ±0.03
13	Hillam-Monk Fryston (In survey area)	30.6	16	Upper Magnesian Limestone	1.90 ±0.16

old quarries at the roadside provide ample opportunity for weathering agents to attack the rock along such lines.

No measurements on the Upper Permian Marls were possibly due to lack of outcrops as it is hidden by drift and there is an absence of borehole cores. However it is almost identical in character to the Middle Permian Marls and results and conclusions obtained for the latter are considered equally applicable.

METHOD D

The measurement of the change of the earth's gravitational attraction with depth in a mine shaft appears to be the most satisfactory method known of finding the density values *in situ* of the rock through which the shaft has been sunk. This fact has led to investigation in the last few years into the design and development of a borehole gravimeter. In passing through a layer of rock its downward attraction is changed to an upward one and the magnitude of this change depends on the density of the layer of rock. If other factors which cause change e.g. effect of surface terrain, effect of elevation from an arbitrarily chosen datum plane can be calculated and eliminated, we are left with a relation:

$$\rho = \Delta g / 4\pi K \Delta R$$

where,

ρ is the density of a layer of rock of thickness ΔR—
Δg is the corrected gravity difference across the layer
K is the gravitational constant.

Full discussions of the method and its application have been made by Hammer (1950) Rogers (1952) and more recently by Domzalski (1954) and (1955). It was carried out in the shafts of Fryston colliery and Prince of Wales colliery near the survey area (Figure 3). Observations were made in the insets and seams being worked from two shafts at each colliery, the readings being taken in a circuit down one shaft and up the other. The instrument used for this (and for other field work referred to earlier) was a Worden gravimeter serial number W-85. The smallest scale division corresponds to approximately 0.011 mgal. but the final accuracy of measurement is of the order of 0.05 mgal. due to instrumental drift.

At Fryston colliery the circuit closed without error, but at the Prince of Wales circuit a closure error of 0.07 mgal. had to be corrected. Considering the changes of temperature and pressure, and the difficult reading conditions, this is acceptable. Sections of the shafts are indicated in Figure 6 and detailed results are given in Tables IV and V. The discrepancy noted between the results obtained for the first layer in the two shafts of the Prince of Wales

TABLE IV

SHAFT SURVEYS PRINCE OF WALES COLLIERY

No. 2 Shaft

Station	Uncorrected gravity (mgals)	Depth below surface station (ft)	Free air corr. (mgals)	Terrain corr. (mgals)	Shaft corr. (mgals)	Excavatⁿ corr. (mgals)	Final gravity (mgals)	Difference of gravity Δ g (mgals)	Difference of elevation Δh (ft).	$4\pi K\Delta h$	Interval density ρ	Cumulative density
1	6.06	—	—	+0.02	+0.09	—	6.17	—	—	—	—	—
2	13.45	236.8	—22.27	+0.06	—	—0.06	—8.82	14.99	236.8	6.0497	2.48	2.48
3	27.76	703.2	—66.14	+0.15	—	—0.07	—38.30	29.48	466.4	11.9154	2.47	2.48
4	33.37	891.8	—83.88	+0.19	—	—0.07	—50.39	12.09	188.6	4.8183	2.51	2.48
5	40.33	1134.2	—106.68	+0.22	—	—0.06	—66.19	15.80	242.4	6.1928	2.55	2.50
6	47.83	1385.4	—130.31	+0.25	—	—0.06	—82.29	16.10	251.2	6.4176	2.51	2.50
7	49.83	1455.9	—136.94	+0.27	—	—0.04	—86.88	4.59	70.5	1.8011	2.55	2.50
8	55.74	1667.7	—156.86	+0.28	—	—0.04	—100.88	14.00	211.8	5.4110	2.59	2.51
9	63.04	1924.8	—181.05	+0.29	—	—0.08	—117.80	16.92	257.1	6.5683	2.58	2.52
10	69.34	2150.2	—202.25	+0.29	—0.09	—0.05	—132.76	14.96	225.4	5.7584	2.60	2.53

No. 1 Shaft

Station	Uncorrected gravity (mgals)	Depth below surface station (ft)	Free air corr. (mgals)	Terrain corr. (mgals)	Shaft corr. (mgals)	Excavatⁿ corr. (mgals)	Final gravity (mgals)	Difference of gravity Δ g (mgals)	Difference of elevation Δh (ft).	$4\pi K\Delta h$	Interval density ρ	Cumulative density
15	5.54	—	—	+0.02	+0.14	—	5.70	—	—	—	—	—
14	13.89	249.2	—23.44	+0.06	—	—0.06	—9.55	15.25	249.2	6.3665	2.40	2.40
13	40.11	1133.0	—106.57	+0.22	—	—0.06	—66.30	56.75	883.8	22.5790	2.51	2.49
12	47.59	1385.5	—130.32	+0.25	—0.08	—0.06	—82.54	16.24	252.5	6.4508	2.52	2.49
11	63.40	1939.3	—182.41	+0.29	—	—	—118.95	36.41	553.8	14.1483	2.57	2.52

Table V

Shaft Surveys fryston Colliery

No. 2 Shaft

Station	Uncorrected gravity (mgals)	Depth below surface station (ft)	Free air corr. (mgals)	Terrain corr. (mgals)	Shaft corr. (mgals)	Excavat^{n} corr. (mgals)	Final gravity (mgals)	Difference of gravity Δg (mgals)	Difference of elevation Δh (ft)	$4\pi K\Delta h$	Interval density ρ	Cumulative density
1	7.38	—	—	+0.03	+0.10	—	7.51	—	—	—	—	—
2	18.03	313.9	—29.53	+0.03	+0.01	—0.07	—11.53	19.04	313.9	8.0194	2.37	2.37
3	25.25	557.7	—52.46	+0.09	—	—0.08	—27.20	15.67	243.8	6.2285	2.52	2.44
4	32.99	818.0	—76.94	+0.15	—	—0.08	—43.88	16.68	260.3	6.6501	2.51	2.46
5	40.66	1094.0	—102.90	+0.21	—	—0.08	—62.11	18.23	276.0	7.0512	2.59	2.49
6	47.54	1343.1	—126.33	+0.27	—	—0.08	—78.60	16.49	249.1	6.3639	2.59	2.51
7	54.13	1575.8	—148.22	+0.31	—	—0.10	—93.75	15.15	232.7	5.9450	2.55	2.52

No. 1 shaft

Station	Uncorrected gravity (mgals)	Depth below surface station (ft)	Free air corr. (mgals)	Terrain corr. (mgals)	Shaft corr. (mgals)	Excavat^{n} corr. (mgals)	Final gravity (mgals)	Difference of gravity Δg (mgals)	Difference of elevation Δh (ft)	$4\pi K\Delta h$	Interval density ρ	Cumulative density
16	7.50	—	—	+0.03	+0.10	—	7.63	—	—	—	—	—
15	18.16	316.14	—29.74	+0.03	+0.01	—0.08	—11.62	19.25	316.14	8.0756	2.38	2.38
14	24.98	548.50	—51.59	+0.09	—	—0.08	—26.60	14.98	232.4	5.9373	2.52	2.44
13	32.89	819.90	—77.12	+0.15	—	—0.08	—44.16	17.56	271.4	6.9336	2.53	2.47
12	40.46	1086.90	—102.23	+0.21	—	—0.08	—61.64	17.48	267.0	6.8212	2.56	2.49
11	47.48	1340.00	—126.04	+0.27	—	—0.08	—78.37	16.73	253.1	6.4661	2.59	2.51
10	56.13	1635.85	—153.87	+0.31	—0.04	—0.08	—97.55	19.18	295.9	7.5596	2.54	2.52

colliery is attributed to a possible error in reading due to particularly difficult reading conditions and to an unapplied correction for a known adit driven near the surface of number 2 shaft, for which no dimensions were available.

The results show a definite increase of density with depth within the Coal Measures. For use in gravity anomaly interpretation, the computation of the effect of theoretical geological sections is simplified if the strata can be divided into definite layers, each having a particular density. An examination of the results obtained show that this is possible to a certain degree. The results from number 2 shaft of the Prince of Wales colliery indicate three possible divisions. These are:

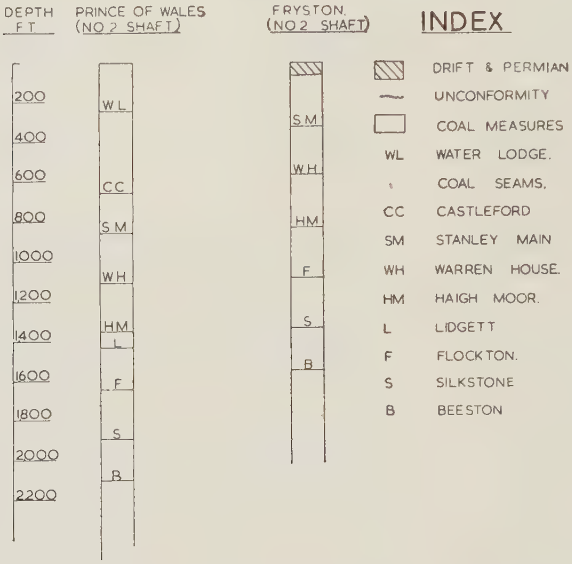


Fig. 6. Shaft Sections.

(1) For the beds below the level of the Lidgett Coal 1,455 ft. below surface level a density of 2.59 grams/cc.

(2) For the strata between the Lidgett Coal and the Castleford Four-foot Coal, a thickness of 752 ft., a density of 2.52 grams/cc. and

(3) For the measures above the Castleford Four-foot Coal, another 703 ft., a density of 2.47 grams/cc.

The results from Fryston Colliery support this division for the 2.52 and 2.59 layers. Only 37 ft. of Coal Measures above the Castleford Four-foot Coal are present and hence no support for a 2.47 layer is forthcoming.

CORRELATION OF THE DIFFERENT METHODS

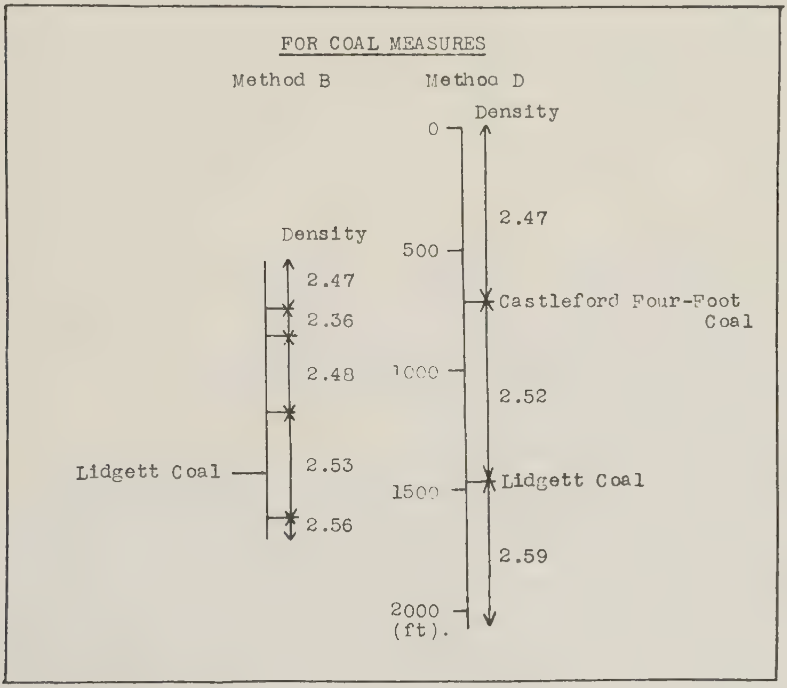
(a) *Coal Measure beds*

Methods B and D permit a comparison of a field and a laboratory method for density determinations on a series of shales and sandstones. The results as shown in table VI indicate in both cases a definite increase of density with depth but the density values recorded by the laboratory method are consistently lower than those from coal mine shafts. The Lidgett Coal dividing the 2.52 and 2.59 zones of the shaft measurements was met at a depth of 1,670 ft. in the Kellington borehole and hence is 275 ft. into the 2.53 zone of the borehole divisions. These results are in agreement with those obtained by Hammer

TABLE VI

Comparison of Methods

Rock Formation	Method A		Method B		Method C	
	Sat.	Range	Sat.	Range	Sat.	Range
Lower Red Sandstone	-	-	2.22	2.15-2.25	1.90	1.80-2.07
Upper Magnesian Limestone	2.48	2.28-2.68	-	-	2.35	-
Middle Permian Marls	-	-	2.53	2.33-2.91	2.57	2.51-2.64
Lower Magnesian Limestone	2.39	2.23-2.49	2.52	2.34-2.64	2.36	2.23-2.50



All densities in grams/c.c.

(1950) in a similar comparison of density determinations over a series of predominantly shale beds. He concluded "that the discrepancy between the density determinations is probably to be attributed to drying or other changes possibly mechanical associated with the core drilling itself, in the samples". It is considered that the results presented here support this conclusion and that the higher average result obtained by method A is further possible evidence that samples obtained by core-drilling do have their densities considerably changed.

In a series of Measures such as described it would appear that the core drilling effect is approximately the same for each core sample. Hence though results are lower than the true values the relative differences are the same. Therefore for an interpretation of a gravity survey involving only beds of these lithologies both methods of density determination are satisfactory if taken by themselves though where possible the shaft method is definitely preferable.

The slightly higher values, of the order of 0.01-0.02 grams/cc. obtained for the core samples over those for the non cores are probably due to the saturating in vacuo of the core samples. However no great advantage from the point of view of relative values seems to have been derived from such treatment and it is concluded to be unnecessary provided that the beds are of similar lithology.

(b) *Lower Magnesian Limestone beds*

The average density and the density range found from both Methods A and C agree very closely with each other. However these values do not compare with the much higher values obtained by the measurements on borehole samples. The difference though large is considered to be due to the effect of weathering on these beds. The quarry samples and the hills are both under weathering influence but not the samples from depths of the order of 500 ft. in a borehole. The difference in physical appearance between such borehole samples and quarry samples is considerable. The dolomite from depth has a more crystalline appearance with considerable gypsum and anhydrite. When it comes from within 300 to 400 ft. of the surface many cavities are found and the effect of free water circulation is apparent. The value of 1.90 grams/cc. obtained from the upper Magnesian Limestone of the Hillam-Monk Fryston hill is an indication of the effect of such weathering on the *in situ* density of these strata and geologists with quarrymen of long experience consider the upper Magnesian Limestone more resistant to weathering than the Lower Magnesian Limestone of this area. It is therefore concluded that the densities found for such beds by laboratory measurements on quarry samples or by the hill surveying method are not reliable for use in the interpretation of a gravity anomaly map where the anomalies might be caused by contrasts at depths between such strata and others. If the survey is across an area where such beds are close to the surface, as in the case of the survey that we have carried out, then it is inferred that a horizontal density gradient, i.e. an increase in density value with distance from outcrop, must be used.

The correlation between the laboratory measurements on quarry samples and results from hill surveys agree with results obtained by Parasnis (1952) but two factors must be remembered; firstly his surveys were done over much larger hills and hence both the weathering effect and that of drift variations would be correspondingly smaller. Secondly, his results do not include measurements on this type of rock. The danger of accepting his conclusion that "laboratory measurements on rock densities will be sufficiently accurate even if hill measurements are dispensed with" without careful consideration of the factors described above is indicated by these results. Parasnis was careful to point out that his results only applied to the Western Midlands of Great Britain. In a survey carried out by this Department over the Coal Measures of South Wales the higher value of 2.65 grams/cc. was adopted for sandstone and shale beds from laboratory and hill survey methods. There is no evidence for such a value for the density of the Coal Measures of North East Yorkshire and the error of any such assumption is obvious. White (1948) in discussing regional gravity anomalies over North East Yorkshire uses a density value of 2.75 grams/cc. for the Permian Limestone. This seems surprisingly high from the results we have obtained but could be explained by an increase in the percentage of anhydrite (density 2.90 grams/cc.) present in the series.

(c) *Marl Beds*

The wide range of densities obtained from laboratory measurements indicates the dependence of obtaining a true average density value for these beds on an accurate knowledge of the percentages of anhydrite and gypsum present. These percentages vary from area to area and are a third factor which will effect the reliability of hill survey measurements. The importance of obtaining more than one result from the latter method is obvious. Considering these factors one can only say that the results indicate that a slightly higher value is obtained from the hill surveys but that this may be misleading if the value of 2.68 grams/cc. obtained for a borehole specimen of almost pure marl (see page 3.) is considered more appropriate.

(d) *Poorly Cemented Sandstones*

The results of hill surveys over this type of rock have been consistently lower than from laboratory measurements. This is again considered to be due to weathering effects and also in part to the high porosity of the rock. The hill results compare better with the dry density of 2.00 grams/cc. found by measurements on a few borehole samples as described earlier. It may be significant that the hill surveys were carried out towards the end of a remarkably dry weather period. The actual gravity survey was carried out during a very wet period and hence in accurate work some allowance must be made for the saturated state of the rock. This becomes significant in the present case where a change of the order of 10% between dry and saturated densities is recorded for these rocks and the fact that they occur close to the surface in the survey area.

In an endeavour to establish some idea of the possible magnitude of the weathering effect on such rock the measurements on the samples from the Pollington water borehole were carried out and, as indicated, a much higher average value was recorded.

In conclusion Hammer has compared results obtained from borehole samples and mine shaft measurements. Parasnis has compared measurements on quarry samples with results from hill surveys and shaft surveys. The results presented here cover all four methods for a somewhat different series of rocks. Apart from the method of measuring the vertical change of gravity in a shaft the other methods are considered not very satisfactory and the values of the results obtained from them must be assessed carefully before they are accepted for use in gravity survey interpretation.

Application to the Surveyed Area

From the results of the density measurements only those relating to the Coal Measures were considered to be satisfactory. The others indicated a horizontal density gradient for the Permian beds and a range of 1.90-2.35 grams/cc. for the Bunter sandstone. The problems of solving the value of the density gradient and that of finding the correct density to be used for the Bunter remained, and the survey evidence was used to solve them. The surveyed area included a section of ground that had been well explored by boreholes and hence was reasonably well known geologically.

Five boreholes put down by the National Coal Board enabled Section 1 (see Figure 7) to be drawn. The control of the geology by the boreholes is such as to make almost impossible any alterations which would affect the surface gravity picture. However the computed gravity change along such a section assuming the three Coal Measure densities established from the shaft measurements, a constant density of 2.53 grams/cc. for the Permian and one of 1.90 grams/cc. for the Triassic (dash-dot line in Figure 7), cannot be correlated with the observed change. At the eastern end it is in error by some 0.70 mgal. If the maximum value of 2.35 grams/cc obtained for the density of the Triassic by method B is used the discrepancy is reduced to 0.28 mgal.

but it is still present. The density of the Triassic is assumed constant over the survey area as it is never found below 150 ft. of the surface so this discrepancy is attributed to using a constant density for the Permian. To establish the best value for the Triassic rocks and hence the magnitude of the Permian density gradient another section, intersecting section 1 was drawn. Borehole data gave fair but not complete control over this section. By using different values for the density of the Trias, within the limits determined by the density determinations, along with the computed density change for the Permian the values which produced the best fit of observed and calculated anomalies along both sections were found. This gave a density value of 2.20 grams/cc. for Triassic rocks and a change of 0.06 grams/cc./mile along section 1 for the Permian beds. The latter change was a little more along section 2 indicating that the direction of maximum change was nearly that of the bisector of the acute angle between these sections, which gives it a W.S.W.-E.N.E. direction. This is at right angles to the escarpment outcrop of the Upper Permian Limestone and Middle Permian Marls approximately two miles away to the west, a fact which supports the conclusions drawn.

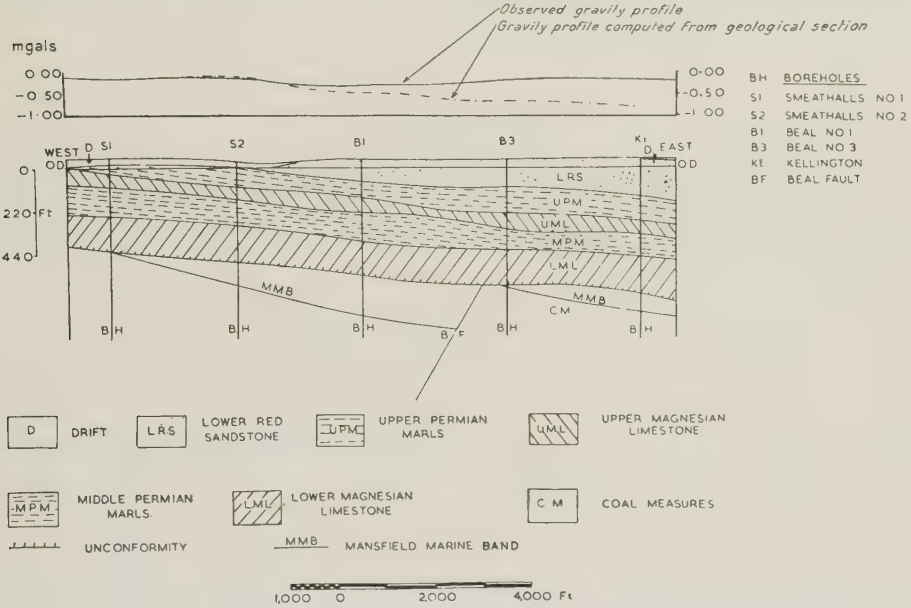


Fig. 7. Section I; geological section and gravity profile.

These values were then applied to the remainder of the survey area and resulted in a satisfactory interpretation in terms of local structures known to be present in the area, and also the location of some which were previously unknown.

ACKNOWLEDGMENTS

The authors wish to record their thanks to the National Coal Board for financial support and permission to use their borehole data. We are also grateful to Mr. Goossens (District Geologist N.C.B.) for his help and advice and to the colliery managers who gave us every assistance with the shaft measurements. Finally we wish to thank Mr. A Hicks for his valuable help with the laboratory determinations and field surveying work.

DISCUSSIONS

L. H. TARRANT: Would the author please explain the distinction between "core" and "non-core" samples and confirm that these samples were all from core-holes?

R. SMITH: The distinction is of importance in Method B, where core and non-core samples were saturated in slightly different ways. By core samples we mean samples drilled and shaped into small cylinders (see fig. 4). This was done to facilitate future resistivity measurements on the samples. Non-core samples were irregular, small pieces obtained by breaking up the original larger borehole samples with a hammer. The samples used in this method were all obtained from core-holes.

O. VECCHIA: Considering the method of measuring densities on rock samples, both from surface and from boreholes, I ask what was the vertical spacing between samples in boreholes?

Whatever this spacing may be, I wish to stress that the differences in lithology between individual layers are great when dealing with such formations as shales, gypsum-marls, mudstones, sandstones, and even many limestones. Sampling will always be an erratic or arbitrary operation. Considering all this, I wonder if one may really put trust in the second figures after the comma, as shown in this paper.

R. SMITH: The samples from Kellington borehole were collected, where possible, from intervals of 10-20 ft. The density values obtained from the laboratory measurements are given to the second decimal place because they are accurate to that figure for the individual samples concerned. When applying the results to the interpretation of gravity surveys that order of accuracy can no longer be contended to exist because of the possible great differences of lithology present and the rapid lateral change of such lithologies, particularly in Coal Measure strata.

The range of densities recorded for particular rock types is then of more value and must always be considered and, we feel, recorded when average densities are used. It is considered that the results presented do indicate that such average values obtained from sampling can, with careful weighting, be taken as accurate to at least ± 0.05 grams/c.c. and probably less if only relative values are required.

F. BREYER: Would it be possible to introduce a correction factor in respect of the compressibility of rocks which is of increasing influence with the increase of depth?

R. SMITH: It would probably be possible to introduce such a correction factor when considering density changes with depth in a great thickness of uniform rock such as a thick limestone or a granite. However, in a complex series of strata as dealt with in this paper, it is doubtful whether such a correction is practicable due to factors such as (a) the different lithologies having different moduli of elasticity, (b) the fact that such moduli change with depth, and (c) the necessity to assume perfect elastic properties for the strata.

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MODERN TECHNIQUE IN SEISMIC REFLECTION RECORDING *

BY

N. A. ANSTEY**

ABSTRACT

This paper is presented to the geophysicist concerned with the taking of seismic records in the field. Part I summarises present knowledge of the fundamental seismic process. Part II details the manner in which this knowledge dictates the selection of some of the parameters available to the operator for controlling the quality of the records. The manner in which the recording problem is changed by the advent of magnetic recording and of automatic record computation is also discussed.

PART I

The very first paper presented in Geophysics (Blau, 1936) was on the subject of black magic. The instrument operator of today, confronted with a maze of controls inside the recording truck and a wide range of variables outside, may well wonder to what extent black magic has been eliminated in the last twenty years. Nurtured on generalisations (which, he is told, often do not apply), he goes to the field to find the best shooting technique by methods which may seem to be largely cut-and-try, and when he is asked to make a certain change the reason for it may not be very clear to him. The purpose of this paper is to summarise and assess what is known of the factors which determine the optimum selection of the many available parameters.
To accomplish this, it appears essential to summarise what is known of the fundamental seismic process.

THE SEISMIC PROCESS

The principle of the seismic method is to apply a stress and measure a quantity related to the strain; it is unfortunate that the relation between stress and strain, for materials encountered in the earth, has not yet been accurately defined. The classical relation (Hooke's law) certainly is not sufficient; a better approximation accredited to Stokes and applied by Ricker (1940, 1941, 1944, 1951) yields results more in accord with observation. Recently, Collins and Lee (1956), in detailing one or two discrepancies in previous work, have stated the need for a more general stress-strain relationship.

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*) Presented at the Tenth Meeting of the European Association of Exploration Geophysicists, held in Hamburg, 16-18 May 1956.

**) Seismograph Service Limited, London.

The view of the seismic process employed in this paper owes much to the researches of Ricker, and is believed to be in accord with all the documented *experimental* work on pulse initiation (notably that reported by Duvall, 1953, Gaskell, 1956, Grant, 1950, Morris, 1950, Ricker, 1940, 1951, and Sharpe, 1942). In fairness, it must be stated that this view is not fully in accord with the construction put upon their results by one or two of these authors. It will be appreciated that the conclusions of this paper may readily be adapted to conform to any future clarifications of the mechanism of pulse transmission in the earth.

The detonation of an explosive charge in a shot-hole produces, within a period of the order of a hundred micro-seconds, gas pressures so intense that the material around the charge is fractured and permanently distorted—an actual cavity is formed. Even beyond this cavity, the peak stress reached in the short outward-travelling pulse of compression is beyond the range of the material's normal stress-strain relationship, and may remain so for several feet from the charge. The radial distance at which the peak pulse stress falls just within this range defines what has been termed the *equivalent cavity*. Within the equivalent cavity, therefore, the normal laws of pulse propagation in the earth do not apply; for this reason the equivalent cavity, rather than the shot itself, is conveniently regarded as the source of the seismic impulse. Within the equivalent cavity the attenuation is very high, and the pulse changes from a pure step near the charge to an almost triangular form (having a fairly sharp rise and a slower decay) at the edge. In a consolidated material the breadth of the pulse at the edge of the equivalent cavity may be of the order of a millisecond; at travel times of interest in seismic prospecting this is sufficiently small to allow the pulse to be taken as the simple impulse or spike which constitutes the starting-point of Ricker's wavelet theory.

Thereafter, the pulse changes form (toward symmetry about its centre) and broadens to a degree depending on the medium of propagation and some function of the travel time (in shale, at least, the square root).

These facts are illustrated, in a very general way, in figure 1. Neither axis, of course, is accurately scaled. The symmetrical pulse shown as associated with later reflections, when differentiated by a moving-coil geophone, is the familiar Ricker velocity wavelet.

If the pulse, in the course of its propagation, encounters a geologic section which includes a formation overlain by another of different acoustic resistance (as when a shale overlies a massive limestone, for instance), a reflection will occur. The reflected pulse may have as much as half the amplitude of the incident pulse; if the reflector is plane and the incidence near normal, there will be no significant change in the shape of the pulse. Accordingly a pulse will be received at the surface of the earth after a certain time; the form and

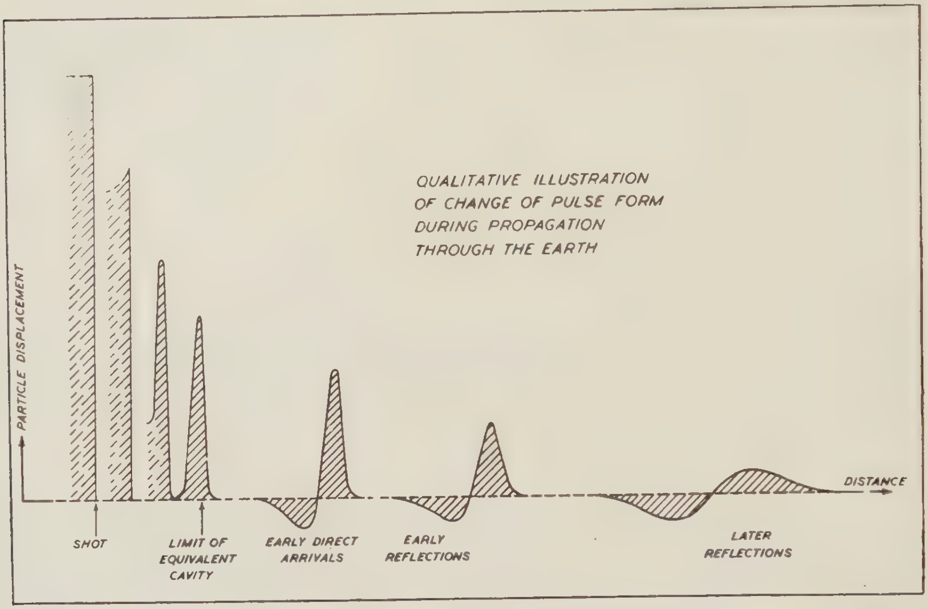

Fig. 1. Qualitative illustration of change of displacement pulse form during propagation through the earth.

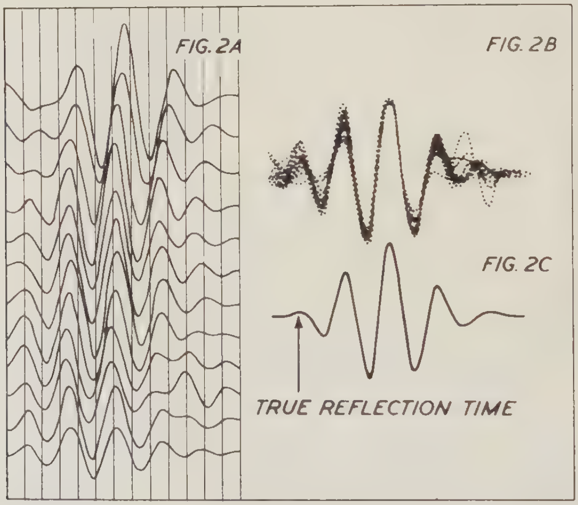

Fig. 2. A recorded reflection waveform, in the presence of noise, compared with its pure idealised counterpart.

breadth will be related to the travel time. The form of the pulse will then be distorted by the seismic recording instruments (Ricker, 1945, Anstey, 1956), and the distorted and lengthened form will then appear on the seismograph record as a well-aligned and continuous reflection.

That this ideal state of affairs can exist in practice is demonstrated in figure 2. The individual traces which evince the alignment shown in figure 2(a) have been scaled to identical maximum amplitude and plotted one on top of the other, in a corrected time relationship, in figure 2(b). Below these traces, in figure 2(c), is a plot of the response of the instruments used to a Ricker velocity wavelet of peak frequency 37 c.p.s. In a case such as this it is possible to state authoritatively the true travel time to the reflector and back, and often to determine whether the reflection comes from an interface across which there is an increase or a decrease of acoustic impedance.

No field geophysicist needs to be reminded that this does not represent the general case. Why not? What is it that makes one record good and another record poor? The answers to these questions concern the nature of the geological series, scattering from inhomogeneities, the region near the shot, surface waves, the low velocity layer, and the geophone plant; these will now be discussed in turn.

The Geological Series

It is well known that the amplitude of a pulse reflected from an interface depends, to a sufficient approximation, on the product of density and longitudinal velocity for each of the two materials in contact. Considerable interest centres on whether the effect of the density variation can, in practice, be neglected; this matter has been discussed by West (1945) and Peterson *et al.* (1955). Without going into this point, it seems certain that consideration of velocity contrasts alone would lead one to expect a few reflections that would not be obtained, and to record a few that were not expected. Accordingly, the ability of the lithologic series to give rise to seismic reflections is expressed, in a measure, by the continuous velocity log. A specimen log, covering a few hundred metres, is illustrated in figure 3. Every change in velocity shown by the log may be taken as initiating a reflection: a large change—a strong reflection, a small change—a weak reflection. It is immediately obvious that, although strong pure reflections do occur, there is a considerable amount of energy returned to the surface by hundreds of minor velocity contrasts. Each such velocity contrast may be thought of as originating a pulse whose amplitude and sense depend on the magnitude and sign of the contrast, and whose breadth depends on the travel-time and the various propagating materials previously encountered. Obviously, these are perfect conditions for interference between pulses, and one of the chief features of continuous velocity logging and record synthesis has been the demonstration that such interference effects are very common. Many early workers (e.g. Beers, 1941) considerated that the correlatable "character of a reflection" represented an interference pattern, rather

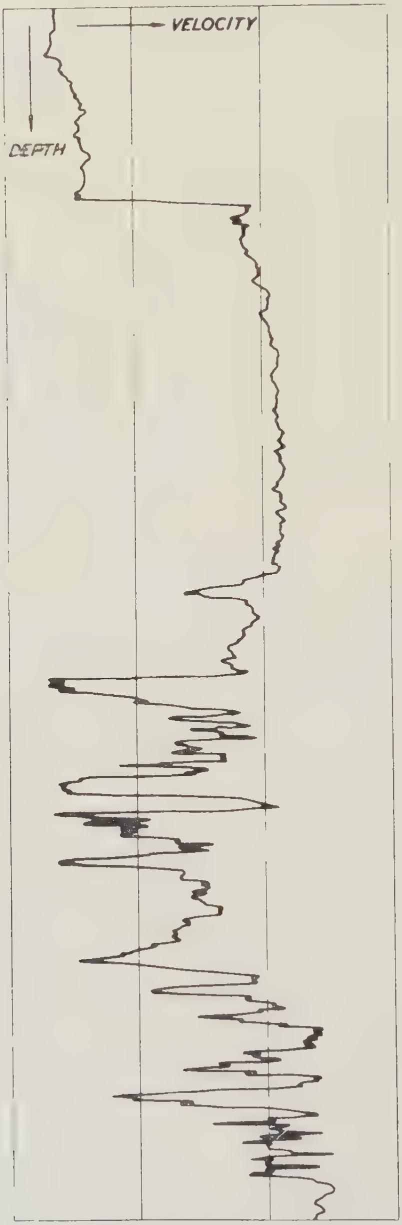

Fig. 3. Illustrative continuous velocity log.

than some feature of the reflecting material—this is now established beyond doubt (Woods, 1956).

The criteria for interference are, obviously, the distance between individual reflectors, the sign of the reflection coefficients, the angle of incidence, and the length of the pulse when it reaches the surface (*NOT its length at the time when reflection occurs*). In this last connection, the field geophysicist will appreciate how much more helpful it is to visualise interference in terms of broadening pulses rather than in terms of sine-wave components. The concept of one pulse being straightforwardly added to another displaced in time, as detailed by Dix (1952, p. 220), is accurate and simple to visualise; the concept of sinusoidal components, though essential to mathematicians and convenient to instrument designers, is artificial and sometimes even dangerous (as when it is used to indicate that in seismic work the reflection coefficient of one interface may be made identically zero by another below it (Clewell and Simon, 1950)).

Since the length of the pulse in the earth is one of the criteria for interference, an important distinction may be drawn between pure reflections from a single velocity contrast and interference-complexes from patterns of velocity contrasts. This is, that if the pulse length is increased, the amplitude of the pure reflection will not vary, while the average amplitude, and the form, of the interference complex may vary within wide limits. Under such conditions, then, a pure reflection will generally be characterised by good continuity, while a complex may lose amplitude and then reappear.

Interference effects which are significantly harmful to record clarity are those arising between pulses reflected from inclined beds, from curved and corrugated interfaces, and from the sides of basins, and between pulses normally reflected and those diffracted and reflected from faults. Indeed, it is such interference effects which furnish the ultimate limitation, in many areas, of the reflection seismograph in its present form (Savit, 1950, footnote p. 226, Dix, 1952).

Because the existence of interference patterns will be noted in several contexts in this paper, it is here pointed out that they normally imply a decrease in resolution. Therefore deliberate attempts to secure the additive reinforcement of pulses can be justified only when such makes possible the picking of information which otherwise would not be represented.

Scattering from Inhomogeneities

We have seen that the nature of the geologic series is such that a seismograph trace will consist of a succession of reflected pulses which will ordinarily overlap. If all the geologic interfaces are continuous, then the same pulses will occur on all traces of the record but their spacing will vary in a measure related to the angle of incidence. When some of the interfaces are not continuous, however, then there will be no correlation of the scattered pulses across the record.

A question arises here which may seem academic but is actually of great importance to the observer in defining the limit of usefulness of his filters. It is: how much change in the shape of the pulse is effected by scatterers of the dimensions which exist in practice? Horton (1955) has investigated the noise background of seismograms, and has indicated, from the reasonableness of results consequent on the assumption that scattered pulses and major reflected pulses have the same form, that there is probably not a great change. However, practical investigations of this sort are made very difficult because the pulse breadth is constantly changing down the record anyway, and because of the complicating effects of "ghost" reflections from the base of the low-velocity layer.* What is certain is that the pulse is either substantially unchanged, or it is changed in a manner which can be regarded as the superposition on it of reduced and time-shifted versions of itself, or it is broadened. This point will be resumed in the discussion of filtering.

The Region Near the Shot

This has always been a bugbear to seismologists. Much of the theoretical work seems to have solved the wrong problem, while much of the experimental work is inconclusive or poorly instrumented. However, some features of behaviour are known, and the following physical picture, while doubtless oversimplified, enables these features to be viewed coherently.

When a very small charge is detonated in a borehole the equivalent cavity is very small and the breadth of the pulse emerging therefrom is negligible. Under these conditions the breadth of the resultant pulse in the earth is defined by the law of broadening and the nature of the propagating material. If the law of broadening is similar to that proven for shale (*viz.*, wavelet breadth proportional to square root of travel time), then it is apparent that the nature of the propagating material during the early part of the travel time plays a major part in deciding the wavelet breadth at later times. Thus for a very small charge the peak frequency of the reflected pulses will be increased if the compaction of the shooting medium is increased (by shooting deeper in the same material, or by shooting in a limestone, for instance). Note that this is a completely general effect, consequent on the nature of the law of broadening.

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*) It would appear that Horton's anomalous result that the reflected pulse recorded at 75 ft. is narrower than that at 125 ft. can be explained in terms of the part-differentation of the pulse at 75 ft. by its inverted reflection from the nearby base of the low-velocity layer.

If the charge size is increased somewhat (to one or two pounds, perhaps) the radius of the equivalent cavity becomes appreciable. Within the cavity the strain-stress curve increases in slope with increasing stress (Lampson, 1945, Dix, 1952, p. 337, Peterson *et al.*, 1955); this has the effect of delaying the peak strain relative to the onset of strain, and so of broadening the pulse as shown qualitatively in figure 1. The pulse from the very small charge of the last paragraph would also have broadened in travelling an equivalent distance, of course; the broadening due to the abnormal stress-strain relationships within the cavity is an *additional* effect. In the case of the charge of one or two pounds, the breadth of the pulse emerging from the cavity may be one millisecond or so. Under these conditions the resultant pulse in the earth is the superposition of this emergent pulse and the normal broadening pulse, and its breadth is the sum of the two. Obviously the pulse broadening which occurs within the cavity is negligible (relative to that which occurs in the earth) at all except very small travel-times. If now the compaction of the shooting medium is increased, the peak stress which can be sustained by the medium will also be increased, and so the equivalent cavity will be smaller and the pulse-broadening effect within it will be less. Therefore the normal increase in the peak frequency of the reflected pulses as a more compacted shooting medium is used will be *enhanced*, but to such a small degree that it will not be noticeable.

If the charge size is very large, however, the equivalent cavity will also be large, and the emergent pulse may be five milliseconds long. This will make an appeciable difference to the breadth and character of the reflected pulses, even at the longest travel-times of interest, and therefore to the general character of the seismogram. In this case the use of a more compacted shooting medium, in reducing the breadth of the pulse emerging from the smaller equivalent cavity, will tend to restore the normal small-charge character of the reflected pulses.

These points are illustrated in figure 4. In this figure amplitude variations are ignored; also, for simplicity, the form given for the pulse at the edge of the equivalent cavity is that given by the abnormal stress-strain relationships therein and does not take account of the normal pulse-shaping effect of the same travel in a linear earth.

A direct inference from this discussion is that when large charges are being used in areas where the shooting medium varies from shot-point to shot-point, the changes in pulse breadth may be sufficient to cause the pure reflections to mis-tie, and the interference complexes to change character and timing, from record to record.

The nature of the shooting medium also has an effect on the amplitude of the reflected pulses. Three factors are involved in deciding the amplitude at

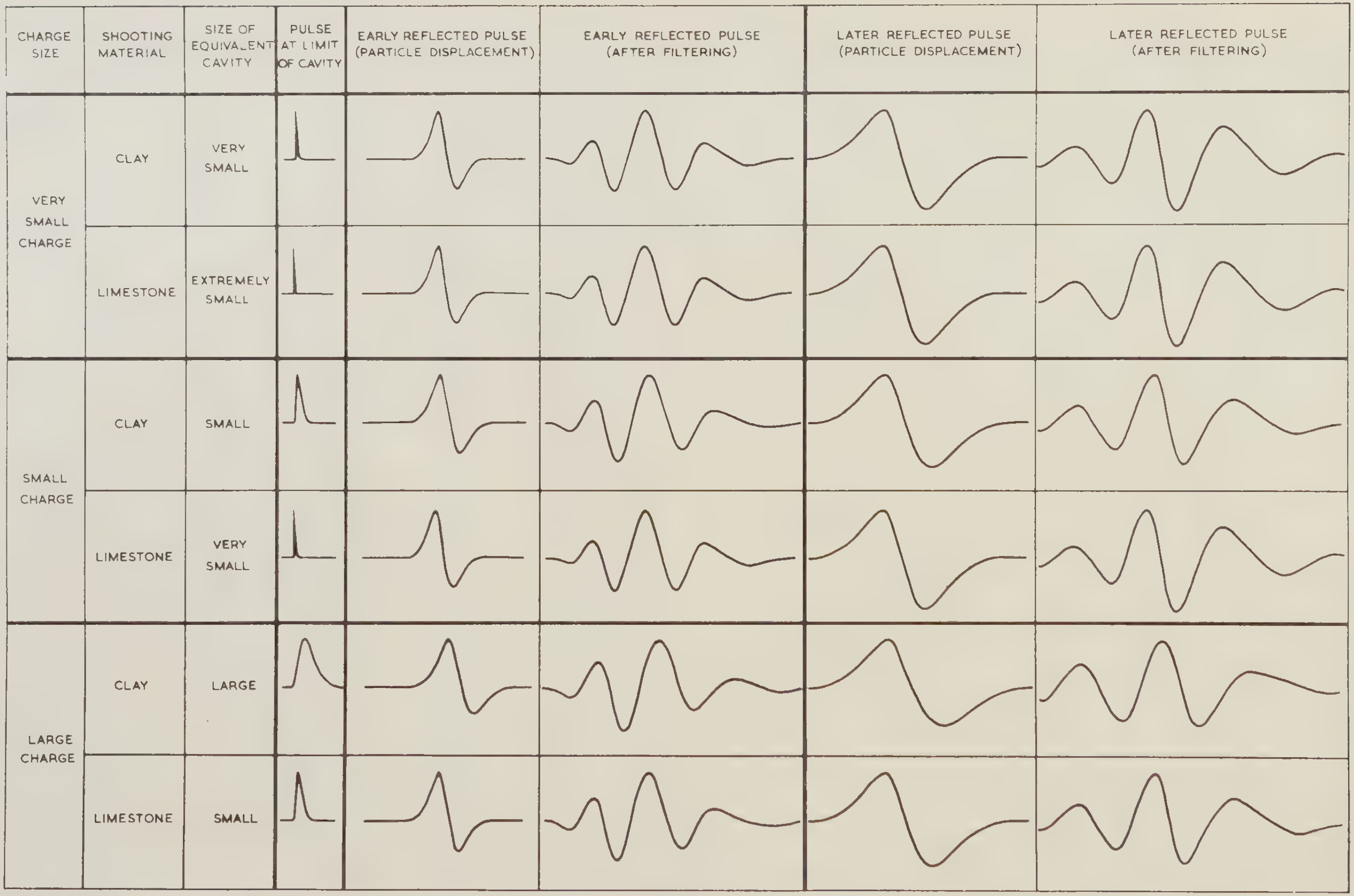
CHARGE SIZE
SHOOTING MATERIAL
SIZE OF EQUIVALENT CAVITY
PULSE AT LIMIT OF CAVITY
EARLY REFLECTED PULSE (PARTICLE DISPLACEMENT)
EARLY REFLECTED PULSE (AFTER FILTERING)
LATER REFLECTED PULSE (PARTICLE DISPLACEMENT)
LATER REFLECTED PULSE (AFTER FILTERING)
VERY SMALL CHARGE
CLAY
VERY SMALL
LIMESTONE
EXTREMELY SMALL
SMALL CHARGE
CLAY
SMALL
LIMESTONE
VERY SMALL
LARGE CHARGE
CLAY
LARGE
LIMESTONE
SMALL

Fig. 4. Qualitative illustration of the effect of variations in shooting material and charge size on the form and timing (amplitude not included) of the seismic pulse.

considerable distance (apart from the normal amplitude decay as some function of the travel time): the peak stress at the limit of the equivalent cavity, the surface area of the cavity, and the breadth of the emergent pulse. The first two tend to cancel each other as the compaction of the shooting medium varies, but the third means that broadened wavelets derived from very narrow pulses (e.g., from a cavity in limestone) will have less amplitude than broadened wavelets derived from broader pulses (because, of course, these may be viewed as a succession of narrow pulses whose resulting wavelets are superposed). Thus the amplitude of reflected pulses will be less from a shot in a rigidly compacted material than from one in a material less compacted, and this holds true even if the breadths of the pulses emerging from the two cavities are, perhaps, a half and one millisecond (so that the change in peak frequency of the reflections is not discernible).

Quite a different state of affairs holds if the shooting medium is aerated. In this case the broadening and attenuating effects in the material are enormous, when the signal level is high, and the resulting reflected pulses are weak and very broad.

Surface Waves

The characteristics of surface waves generated in exploration seismology depend on the nature of the near-surface stratification. Because the latter can vary so much from place to place, a great variety of surface waves is encountered. These include refracted shear waves, coupled air waves, multiply-reflected refractions, normal-mode wave-guide propagation in the low-velocity layer, and, of course, Rayleigh waves (Dix, 1955, Dobrin, 1951, Dobrin *et al.*, 1954, Eisler, 1952, L.G. Howell *et al.*, 1953, B. F. Howell, 1949).

While mock-Rayleigh waves are normally blamed for most surface-wave troubles, it should be borne in mind that conditions in the near-surface stratification are favourable to other types of disturbance in many if not most areas. The Rayleigh waves themselves may consist of a short burst of non-dispersive waves or a long disturbance of either dispersive or apparently inversely-dispersive waves, depending on the stratification. The amplitude of the surface-bounded waves decreases as the depth of the shot is increased, but the amplitude of waves associated with another interface may increase as the shot is placed closer to it.

The redeeming feature about surface waves is that it is fairly simple to get the measure of them. By shooting a normal spread with low-frequency geophones, a.g.c. switched off, high-pass filter switched out, low-pass filter set fairly low, and very low gain, it is possible to get a sufficiently exact picture of the frequency range, phase velocity and time duration of the surface wave groups; then optimum values for depth and size of charge and for filtering and pattern arrangements can readily be found.

The Low-Velocity Layer

The low-velocity layer has an attenuating and broadening effect on the returning reflected pulses, associated with a differential delaying effect from trace to trace if the layer is not of uniform thickness. However, Poulter (1950) has shown that the attenuating effect is not too serious at the small signal levels associated with reflections, while Houghton (1940) has indicated that the effect is more than compensated, for purposes of seismic registration, by the change in acoustic resistance. The broadening effect is not too serious because the travel-times are long, and the differential delay can be partially compensated (Wolf, 1940) by corrections or the intelligent use of a template. Nevertheless, the low velocity layer is a grave impediment to record clarity, chiefly because of the two excellent reflecting interfaces by which it is bounded.

Shugart (1944) has considered the consequences of these excellent reflectors in terms of continuous sinusoids; again it may be more helpful to the field geophysicist to describe their effect simply by saying that to every pulse arriving at the surface there is added an inverted version of itself at perhaps a quarter or third amplitude and then another erect version at proportionately smaller amplitude, and so on. Since every reflected pulse may therefore extend at significant amplitude over 150 or 200 milliseconds, the consequent increase in record complexity is obvious.

When, as is usual, the shot is below the low-velocity layer, the downward-travelling pulse is also complicated by its inverted image reflected from the underside of the layer (Van Melle and Weatherburn, 1953). This effect may sometimes be turned to apparent usefulness by adjusting the shot depth so that by the time the two pulses returned from a certain reflector arrive at the earth's surface they are in the correct relationship for approximate reinforcement. However, the manner in which this criterion should be expressed requires some consideration; this point is discussed further in Part II.

The Geophone Plant

The coupling between the geophone and the ground is a resonant system; the behaviour of this system has been investigated by Washburn and Wiley (1941), Wolf, (1944), and by Pasechnik (1952). The resonant frequency and sharpness of tuning of this system are controlled by features which may seem insignificant to the man who plants the geophones, and in practice there is little hope of preserving these parameters identical from one geophone to the next. The effect of this resonant system is, of course, the same as that of a filter, so that each trace may be distorted and time-shifted by the geophone plant as though each one had been on a different filter setting. Where planting conditions on the spread vary widely, this effect can seriously mar reflected alignments.

PART II

Summary of Record-Depreciating Factors Discussed in Part I

These are, briefly: confusion from minor reflections (and from multiple reflections), uncorrelatable interference patterns, the use of pulse breadths unsuitable for the type of stratification, scattering from inhomogeneities, surface waves, and variations in geophone plant. These factors apply to all traces; factors peculiar to traces near the shot-point are: hole blow, collapse of the cavity, and noise occasioned by granules of the unconsolidated surface layer sliding one on the other. Though it is normally unimportant at the beginning of a record, wind noise assumes major proportions at the end—in fact, it *defines* the end of the record if the instrument sensitivity is correctly adjusted.

A prerequisite of good recording technique, then, is to find out which of these factors is impairing the record quality.

This is done partly by careful record analysis and partly by *directed* experimentation; when it has been done it is possible either to prescribe an optimum technique or to say authoritatively that no better results can be obtained in the area by the reflection seismograph in its present form.

Seismic Reflection Recording Technique

This section is devoted to the application of the above view of the seismic process to the determination of five of the observer's most powerful variables: spread length, multiple patterns, depth of charge, size of charge, and filters.

Several general points must first be made:

(i) The establishing of optimum recording conditions is a scientific process, an application of scientific method. One directed experiment is worth twenty odd cut-and-try records, and, though the observer is constantly plagued by local variations in conditions, the conclusions of a directed experiment are much less liable to result in serious errors than cut-and-try conclusions. There is, therefore, a *correct order* of seismic experimentation, and the observer and party chief need to be men trained in the scientific thinking that will decide this order.

(ii) The scientific method which is most suited to seismic experimentation is *the changing of only one variable at a time.* (Note, however, that changing one variable may involve moving two controls; changing the filter setting to give optimum recording of a narrower pulse involves changing the a.g.c. speed as well (Anstey, 1956).)

(iii) Sometimes one meets in the field an impression that scientific method does not "work" in the seismic industry. This can only be a measure of the inadequacy of the physical picture used as a basis for the method. For instance, the seismic literature abounds in references to lapsed patents which would have worked very well if the seismic impulse were really a sinusoidal wave train already several hundred feet long at its inception!

(iv) It is never possible to provide truly optimum registration of both early and late reflections on the same record. This is so partly because of noise generation near the shot when large charges are used, and partly because the larger charges necessary for recording deep reflections usually involve pulse lengths unfavourable to resolution of shallow reflections. Chiefly, however, it is because a filter adjusted to give optimum registration of an early, narrow reflection will attenuate a late, broad reflection. The field geophysicist is usually a little reluctant to agree that broadening of pulses to the degree stated does actually occur on the record. Apart from the effect of interference patterns (which may result in a false appearance of high-peak-frequency reflections following low-peak-frequency reflections), this is because the filters normally mask this very considerable broadening. Figure 5 illustrates the effect of one filter on primary pulses of three breadths; it is evident that a change of pulse peak-frequency from 50 to 18 c.p.s. results in a change from 40 to 33 c.p.s. in what is normally, *but incorrectly*, termed the "frequency" of the reflection.

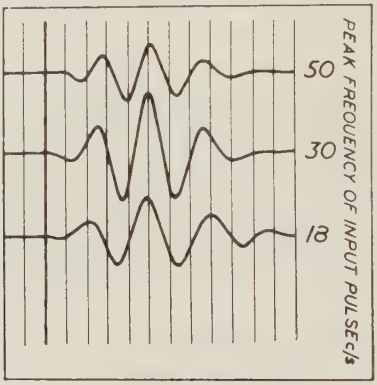

Fig. 5. Illustration of the futility of the term "frequency of a reflection".

Because of this fact that optimum registration of shallow and deep information cannot be obtained on the same record, and because there is a practical and economic limitation to the number of records which may be taken, the nature of the geologic problem should be made very clear to the party chief and the observer, together with any clarifications of it as the work proceeds. When the geologic problem is well defined the field technique may well be quite different from the general compromise.

The Length of the Spread

This parameter is used to identify and correct poor record quality caused by uncorrelatable interference patterns, scattering from major inhomogeneities and, sometimes, surface waves.

The normal considerations defining the spread length are dip accuracy, economy in drilling, economy in cable-laying, and the fact that picking certainty is jeopardised if the step-outs are very large (Jakosky, 1950, Weatherby, 1952, Alcock and Waters, 1947; see also Koefoed, 1955). However, experimental reduction of spread length furnishes a powerful tool for assessing the effect of uncorrelatable interference patterns (as from corrugations, widespread faulting, etc.), and major inhomogeneities. Experimental moving of the entire normal spread away from the shot-point is, of course, the classic method for observing the early part of the record uncomplicated by surface waves and shot-hole noises.

In good areas, production spreads may be permitted to err on the long side; in difficult areas experimental spreads should err on the short side, with the maximum permissible increase for production work determined as the last phase of the experimentation.

Multiple Patterns

This parameter is used to identify and correct poor record quality caused by near-surface inhomogeneity scattering, geophone plant variations, and surface disturbances. Further, in areas where it is difficult to impart a sufficient impulse into the earth, multiple holes facilitate this and multiple geophones lengthen the record by restricting the wind noise.

A fact which does not appear to be stressed in the literature is that the type and size of pattern depends on the function it is desired to perform. Thus the design of patterns for the partial elimination of surface waves has been exhaustively treated; the principles are described and extended in a paper by Parr and Mayne (1955), which includes all the references to that date. But in some areas where surface waves are not a primary problem the use of multiple patterns is necessary for a basically different purpose—the reduction of the effect of near-surface and surface material variations—and for these purposes patterns based on surface-wave considerations may be much too large. In this case the maximum diameter of patterns which will not attenuate the earliest reflection of interest is strictly defined, and considerations of obtaining the maximum distance between the geophones within that diameter result in a complete definition of the optimum pattern (Muir and Hales, 1955).

There are five ways of reducing the effect of surface waves, viz., changing the shot depth, shooting skip-spreads, using multiple patterns, applying electrical filtering with high cut-off frequency and small slope, or applying electrical filtering with low cut-off frequency and steep slope. Which of these is used depends on the geological problem to be solved. If shallow reflectors only are of interest, the best course is to use small patterns and electrical filtering with high cut-off frequency and small slope (moving the spread involves even smaller patterns). If deep reflectors only are of interest, large patterns are indicated; some electrical filtering with low cut-off frequency will still be required because surface disturbances do not have the constant amplitude assumed in pattern design. When shallow reflectors have a greater value than the deep ones, but both are of interest, the best course is to use small patterns (perhaps 30 ft. in diameter) and electrical filtering of low cut-off frequency and steep slope (and to tolerate the resultant distortion of the late events). When deep reflectors have a greater value than shallow ones, but both are of interest, the best course is to use fairly large patterns with less steep filtering. When the entire range is of equal interest, then the only answer is to reduce the amplitude of surface waves generated (by deepening the shot) and to use small patterns.

In some areas where surface and near-surface variations are of large extent, the improved sampling consequent on the use of a pattern larger than the calculated maximum may more than compensate the attendant attenuation of the early reflections.

Patterns of shots may also serve different purposes. If shallow reflectors are of interest, then again the pattern must be small; if the same shot depth is maintained, and provided that the detonation of all shots is simultaneous, then the resultant pulse in the earth may be narrowed and the reflection resolution improved. Conversely, the same pulse length as before may be obtained with somewhat shallower holes. Shallower still, the pulse becomes broader, so that early-reflection resolution is impaired; if this is tolerable the pattern diameter may then be increased to reduce the amplitude of the consequent surface waves.

A particular case for pattern shooting at very shallow depth arises when there is a high-velocity material at the surface. In this case there is no trouble with the breadth of the pulse, but only with the problems of loading sufficient explosive and suppressing the air wave; obviously these can be overcome by the use of many proportionately smaller charges, individually tamped and arranged in a pattern of diameter suited to the geologic problem.

Depth of Charge

This parameter is used to identify and correct poor record quality caused by surface waves, uncorrelatable interference patterns, and pulse breadths unsuitable for the type of stratification.

The four factors which are varied by the depth of the charge are the generation of surface and near-surface waves, the amplitude of the pulse, the breadth of the pulse, and the amplitude and delay of its "ghost". These are treated in turn.

It has already been mentioned that the amplitude of free-surface Rayleigh waves falls off as the shot depth is increased. In the simple case, then, the deeper the better in an area prone to surface waves. However, a complication arises if there are any very good reflectors (in addition to the surface itself) at fairly shallow depths; in such a case boundary waves may be set up at this interface, or, more serious, reverberations may occur between this interface and the surface. Under these circumstances the pulse may be viewed as "trapped" between the two planes; the seriousness of this is obvious. A particular case, of course, occurs when the shot is within the low-velocity layer, but the effect also implies that if there is a very-high-velocity bed below the base of the low-velocity layer, it will often be necessary to drill through it.

From the previous discussion of pulse initiation, it follows that when only one shooting medium is available, the maximum amplitude of the pulse recorded at distance will be obtained when the upper limit of the equivalent cavity is just below the base of the low-velocity layer. Since, on surface wave considerations, it is unwise to err on the shallow side, this normally means that the charge itself is some twenty or thirty feet below the low-velocity layer. When a selection of shooting media is available, however, the largest amplitude of the pulse recorded at distance will be obtained when the shooting medium used is consolidated but not very rigid (e.g., clay, shale, water-saturated sand or silt).

Since the amplitude gained by these methods appears to equal or exceed the amplitude lost in traversing the material of less compaction, the above principles, based on amplitude alone, generally decide the charge depth to be used.

The pulse breadth at every value of travel time will thereby have been determined. However, it may be found that this pulse breadth makes it difficult to follow a particular interference complex of interest. More resolution may be required (deeper charge) or, in some cases, less resolution (shallower or larger charge). In particular, if continuity of the complex is to be maintained, it will be necessary to keep the pulse breadth from every shot the same; this will sometimes involve placing the shot always the same distance below the water table, and sometimes involve placing the shot in the same shooting medium, whatever its depth.

Figure 6 demonstrates how a good reflection complex can show erratic or poor continuity from one record to the next when the shot-point conditions are highly variable. All four traces represent four reflections, alternately erect and inverted, spaced always at 30 milliseconds and having their original centres marked by heavy lines. The only variable is the initial breadth of the pulse as it leaves the equivalent cavity; it can be seen that, in an extreme case, the signal on the bottom trace of one record may show little or no continuity with that on the top trace of the interlocking record, and this for no other reason than that the shooting medium has changed.

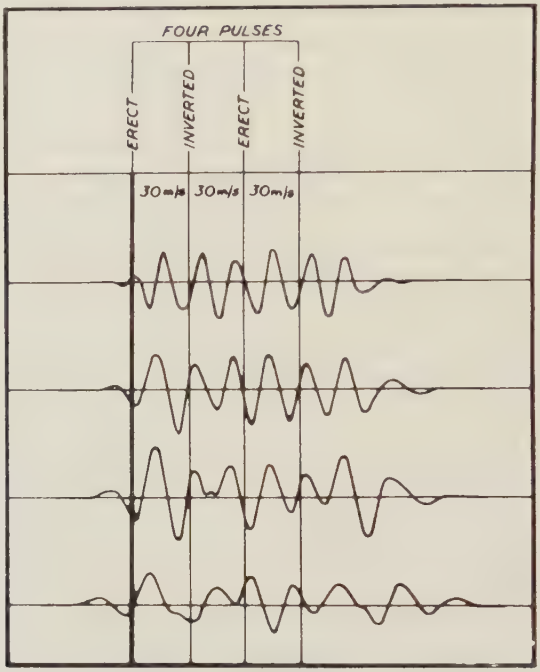

Fig. 6. Illustration of the effect on record-to-record continuity of changes in the characteristics of the equivalent cavity from shot-point to shot-point.

The fact that the down-going pulse is normally followed by a "ghost" reflected from the underside of the low-velocity layer has been mentioned in Part I. However, it remains to state the criterion by which this effect can be made useful. If the geophones record particle displacement and no instrumental filtering is imposed, then the primary pulse has one compression displacement and one rarefaction displacement, while the ghost pulse has a rarefaction displacement followed by a compression displacement. Manifestly the criterion is that the ghost rarefaction should reinforce the primary rarefaction at the time when the reflected pulses reach the surface. From the form of the displacement pulse it is clear that this criterion is not quite the quarter-"wavelength" one proposed by Van Melle and Weatherburn, while from a consideration of the broadening which the pulse suffers it is clear that the effect will cause the loss of reflection resolution for travel times less than that at which reinforcement occurs and also the loss of reflection amplitude at times greater than this. If conventional instrumental filtering is imposed, however, each recorded pulse has several more half-cycles than the original displacement pulse, and different criteria may be available. Indeed, as more and more filtering is imposed, and the recorded pulse becomes more characteristic of the filter and less characteristic of the pulse in the earth, the criterion may become one of an average quarter-period of the filter's pulse response (e.g., the shot would be about $6\frac{1}{2}$ milliseconds below the low-velocity layer for the filter used in figure 5). Thus we have a case where loose and inaccurate conceptions of "frequency" and "wavelength" sometimes encountered in the field among exponents of quarter-"wavelength" shot sitings, actually produce a result which is almost correct.

Therefore there are three points about this technique of siting the charge below the low-velocity layer which should be stressed: that on conventional filtered records there is no simple connection between the reinforcement criterion and the actual length of the pulse in the ground, that misapplication of the technique will lead to the harmful narrowing of the filters for no other purpose than to preserve reinforcement over a greater length of record, and that, when all is said and done, any such reinforcement technique impairs resolution.

Unfortunately the interference effect cannot be eliminated when it is not wanted (except possibly by surface shooting). If extreme resolution is required for a certain geologic problem, then the tendency will be to use very deep shots anyway; then the attenuation between the shot and the reflector above it will render the ghost pulse less significant.

It is obvious that if an interference complex occasioned by or partly involving this effect is to be followed from record to record, it will be very important to keep constant both pulse breadth and the depth of the shot below the low-velocity layer.

Size of Charge

From all the foregoing it is evident that the size of the charge must be determined in conjunction with the depth. Further, it is evident that the relation between charge weight and the amplitude of the reflected pulse will be complex, depending on the dimensions of the cavity both before and after the shot as well as the theoretical relation of energy and amplitude consequent on the shape of the pulse.

When the change of pulse breadth with charge size is negligible over a range of operating conditions, then the charge size is determined as follows:

(i) If the solution of the geologic problem requires information only to a certain time, then the charge should be the smallest which will give information just beyond that time.

(ii) If the problem requires as deep information as can be obtained, then in older equipments the limit of charge size is dictated by the range of the automatic gain control. In more modern equipments the limit is that charge size at which the clarity of the early reflections begins to suffer on account of the lengthening of the pulse and the non-linear generation of noise in the region near the shot.

Filters

The term "filter" is an unhappy one, implying as it does that some things are blocked and others are passed unchanged. It was adopted, of course, in very early days, when the seismic model involved sinusoidal wave trains and reflectors which generated "extraneous frequencies". Filters were said to improve the signal-to-noise ratio, on the assumption that what the trace recorded between reflections was "random noise".

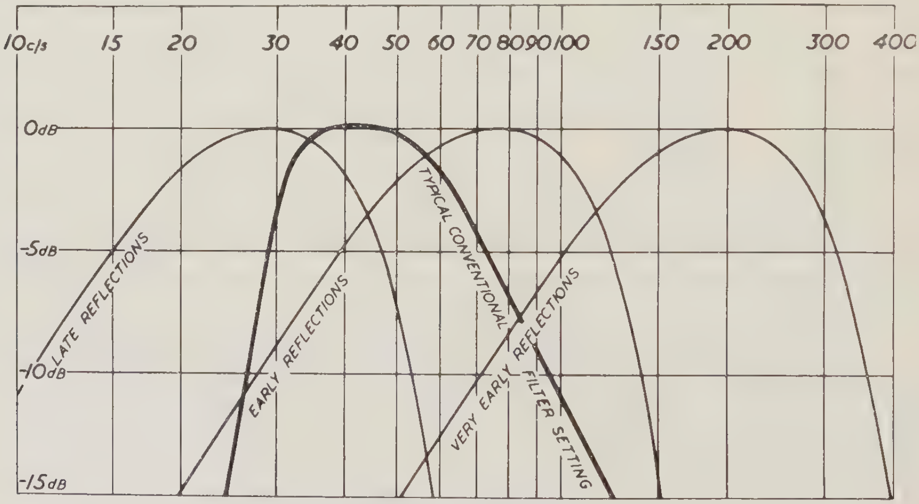

Fig. 7. Approximate reflection spectra.

It is now realised that much of what the trace records between reflections is more reflections, whether from minor velocity contrasts or from inhomogeneities. The rest is surface waves, disturbances associated with the shot-hole and the low-velocity layer, transverse arrivals and thousands of multiple reverberations, and, at the end of the record, wind noise. What are the spectra involved? The spectrum of a pure reflected pulse is defined by the initial pulse breadth, the travel time, and the material traversed. The last item means that a simple reflection at 2 seconds will not have quite the same spectrum as a multiple reflection at 2 seconds, but the difference will generally

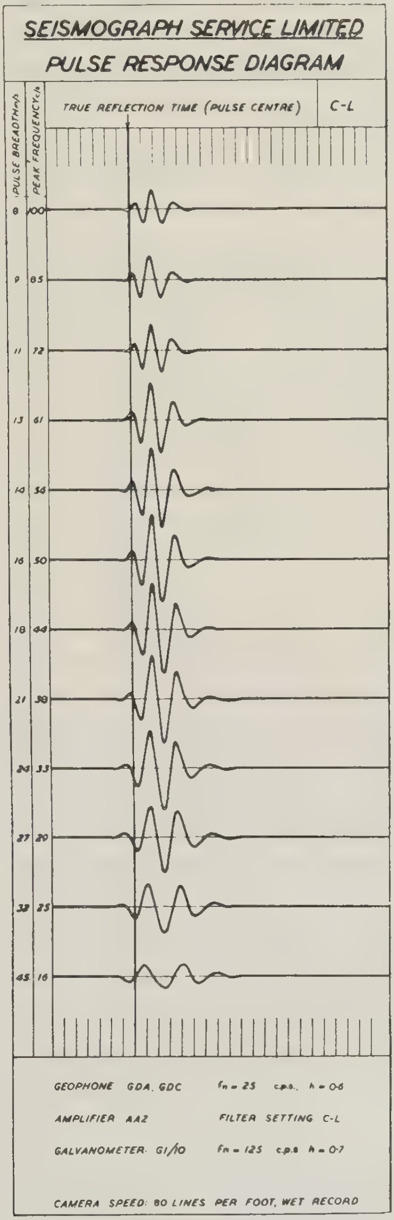

Fig. 8. Specimen pulse-response diagram.

be very small. At any particular travel time, then, all the reflections, whether minor, major, multiple, wanted or unwanted, will have almost exactly the same spectrum, and so *no distinction can be made between them by normal electrical filters*. The sort of spectra involved are illustrated in figure 7. The presence of inhomogeneity scatterers at depth will add pulses either of the same spectrum or of one of slightly lower peak frequency ("slightly", because if the peak frequency is much lower then the amplitude cannot be great).

The usefulness of electrical filters, in their function as filters, is therefore restricted to the attenuation of surface waves and of disturbances associated with the shot and the low-velocity layer. When the surface waves are predominantly Rayleigh waves their spectrum is usually quite narrow. The spectrum of wind noise, hole blow, and noise in the low-velocity layer granules is certainly broader than the pulse spectrum, and can be taken as flat. If the surface waves are serious, then a high-pass filter will have to be set on their account, as discussed under "Multiple Patterns" above. Then the problem is to set the rest of the filtering to give the maximum pulse amplitude relative to the white noise. This is the problem discussed by Muir and Hales (1955); the answer is the use of a filter whose response is identical to the wavelet spectrum.

From figure 7, it is obvious why one filter setting cannot give optimum registration of both early and late reflections. With conventional equipment a compromise must be made, depending in position on the travel-time to which attaches the greatest geological significance. The peak frequency of the filter response should then be near the peak frequency of the pulse spectrum at that time, even if the slopes of the filter response differ from those of the pulse spectrum for any reason. A means for verifying that this condition is met is illustrated in figure 8; the diagram represents the response of the complete recording channel, on a certain filter setting, to Ricker wavelets of the breadths stated. If the waveforms of the diagram are mated with the form of a good reflection at the time of greatest interest, it should be found that the latter coincides with a waveform in the centre of the diagram (i.e. one with high amplitude). If the coincidence comes above this the filter setting is too low, and *vice versa*.

We have seen that much of what was formerly regarded as "noise" cannot be filtered out—it is in fact "signal". Further, in filtering out what *can* be regarded as "noise", there is a point beyond which the filters do no good—they filter out both signal and noise. However, it is a matter of common observation that filters are often used much narrower than even a single pulse spectrum, and that not only on account of surface waves. The answer is, of course, that the filters are then used, not as filters, but as character-formers to *create* interference patterns. This they can do because they spread out each pulse over an appreciably longer time, thereby increasing the possibilities for interference. Figure 9 illustrates such interference; the input signal consists of three identical pulses, two erect and the middle one inverted, and the resultant signal through each of three filter settings is displayed. The part of the waveform on which a pick is most likely to be made moves backwards and

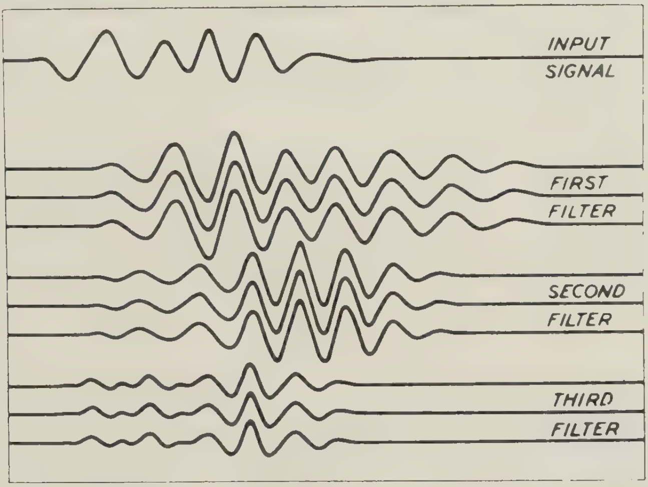

Fig. 9. Illustration of interference effects within the filters.

forwards from filter to filter (Loper and Pittman, 1954, p. 113); it is also true that on one filter setting a change in pulse breadth may cause one "reflection" to disappear and another near it to appear.

It may be asked whether the use of the filters in this way can be justified. Presumably it can, if it enables three or four weak reflections which could not be picked to appear as one which can. However, mis-ties in the compounded reflection must be expected, and the geologic significance of the time at which it is picked is somewhat obscure.

MAGNETIC RECORDING AND AUTOMATIC DATA PROCESSING

The advantages of broad-band magnetic recording where filtering is concerned are self-evident. However, considerations such as those of the last paragraph make it clear that the best place to perform filtering studies is actually on the cross-section, rather than on individual records, the significance of the interference patterns can them be ascertained more readily.

Unfortunately, magnetic recording cannot remove many of the listed causes of poor quality records. This very fact highlights the need for increased knowledge of the mechanism of pulse initiation and transmission, for it is this knowledge which ultimately decides practically every feature of optimum recording technique.

The advent of automatic data processing brings with it a very interesting question: how much of what we now regard as good seismograph practice is actually consequent on the fact that *the eye* is the means of detecting reflections? The eye is upset by an amplitude range of more than a few times, and so we distort relative amplitudes in recording. The eye does not like large step-outs, and so sometimes the spreads we shoot are shorter than they need be. The eye likes to see an alignment spread out over time, and so we use filter settings which are too low. By the same token we sometimes regard as improvements shooting systems which use a succession of pulses (e.g., Poulter, 1950). Time and again we sacrifice resolution for optical clarity. For these reasons we can expect the recognition of reflections by electronic means, and their rigorous grading, to yield results which are of considerably greater geological significance than those presently obtained.

Acknowledgment

The author expresses his thanks to the Directors of Seismograph Service Limited for their assent to the publication of this paper, to Mrs. G. Whittle, who prepared the illustrations, to Mr. Francis Muir, who contributed much of the thought behind the paper, and to Mr. F. W. Hales, who presented it at the Hamburg meeting.

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INTERPRETATION METHOD FOR WELL VELOCITY SURVEYS

BY

DEAN WALLING* and CARL H. SAVIT*

Abstract

"Cable" and other extraneous energy in well velocity surveys may be identified and distinguished from "formation" energy by using phase relationships. Conventional instruments with at least two different narrow band-pass filters provide sufficient data to achieve good results even in the presence of extreme amounts of interference. The method is illustrated by laboratory tests and an actual well survey.

The problem of extraneous energy paths in well velocity surveys has long been recognized by many geophysicists. The principal conductors of such extraneous energy have been found to be the well casing and the cable from which the well seismometer is suspended. The cable as a conductor of seismic energy was always an important factor in well surveys in low velocity areas. The problem did not, however, become general until 1944 when Schlumberger introduced its steel core cable. The higher velocity of waves in the steel core

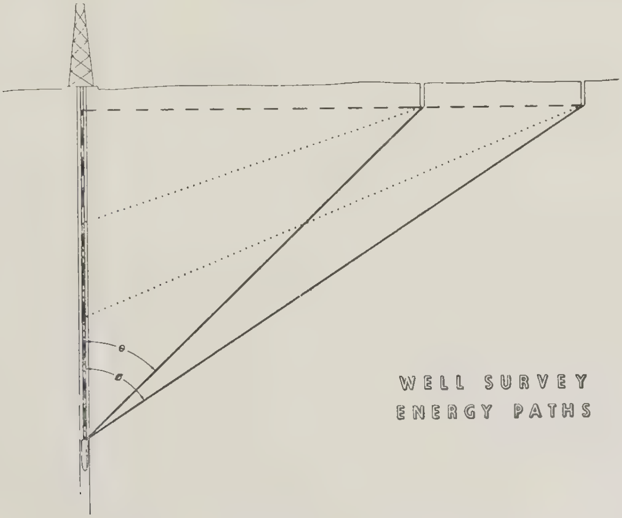

Fig. 1. Two commonly identified extraneous energy paths and the formation path. The formation path is shown by solid lines, the "cable" paths by dotted and dashed lines.

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*) Western Geophysical Company, Los Angeles.

cable has greatly increased the proportion of wells in which surveys suffer from cable "lead".

"Formation" and "cable" paths are shown in Figure 1. Cable energy paths of two kinds have been identified in many surveys. Surface or horizontally traveling *S* waves reach the well and are transmitted down the cable or casing as *P* waves. *P* waves in the formation also enter the cable at the critical angle of refraction.

The present paper will illustrate a method which is proving effective in the interpretation of well survey records. No new or special equipment is required and no major deviation from conventional procedure is necessary.

Previous effort in well survey technique has been directed principally in two directions. The obtaining of a sharp first break has been the primary goal of most survey methods. The result, however, of the high amplitudes used has been to conceal subsequent arrivals. The problem of cable energy has been attacked primarily by designing or suspending the well seismometer so as to minimize the cable energy transmitted to the instrument. Such devices have often proved to be cumbersome and not wholly successfull in eliminating unwanted energy. Within the last two years there has been a gradual introduction of pressure sensitive well seismometers. These instruments have a greatly reduced sensitivity to cable and casing energy but do not entirely eliminate the problem.

The approach of the present method consists of using ordinary instruments in such a way that all energy arrivals regardless of path are detected, timed, and properly identified.

To implement such a method it is necessary, first, to be able to detect each and every energy "pulse" and to establish an accurate arrival time for each. Second, after all pulses on each record have been timed, it is necessary to employ a system to distinguish cable and other arrivals from the desired direct "formation" arrivals.

The method of this paper is first to record the well seismometer energy on four or more traces. The seismometer response is passed through two different filters, and the output of each of these filters is recorded with a low and a high gain. The two low amplitude traces are so adjusted that the entire trace remains at all times completely visible on the record. The high amplitude traces are adjusted to maximum usable gain based on prevailing noise levels. The two filters are chosen so that both are relatively narrow band-pass filters with a separation of peak frequencies that must be neither too small nor too large.

From the low amplitude traces in each filter setting, it is usually quite easy to pick out individual wavelets or wave trains due to separate pulses.

The first and key step, then, is to determine the time of "first arrival" of each pulse. To accomplish this end, we note that a pulse as seen through two different filters will have simultaneous onsets. As time progresses, however, each filter will tend to produce its own characteristic wave form, with its own frequency. Figure 2 illustrates the appearance of a pure pulse as seen through two different filters.

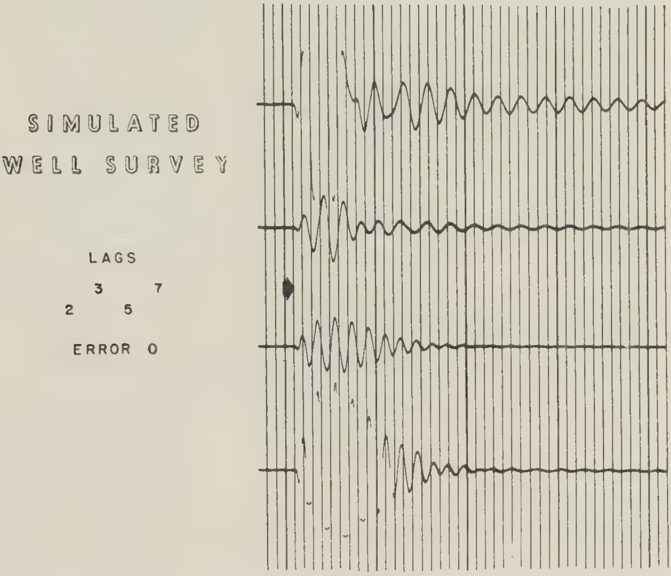

Fig. 2. Single pulse simulation of well velocity survey record. The time differences between the initiation time of the impulse and the several troughs and peaks were observed on several records like this for use in recovering the initiation time of the impulses in Figs. 3-6.

Let us now define the phase lag between two different signals as the time interval between points of corresponding phase angle in each. If we start our time scales together at the time of incidence of a pulse, it is clear that at that time the phase lag is zero. The phase lag is known to be (for the cases of interest in our present context) a monotonic function. If we take our lag to be positive, we can say that it must increase either indefinitely or approach asymptotically a constant value depending on the nature of the input signal. In any event, the phase lag behaves consistently, and hence predictably, within the limits of experimental error.

It is thus a simple matter to deduce from the observed phase lags of corresponding peaks and troughs the number of cycles beyond the initial impulse represented by each peak or trough. From the known period for each filter used, the time of the initial pulse may be accurately determined. In practice

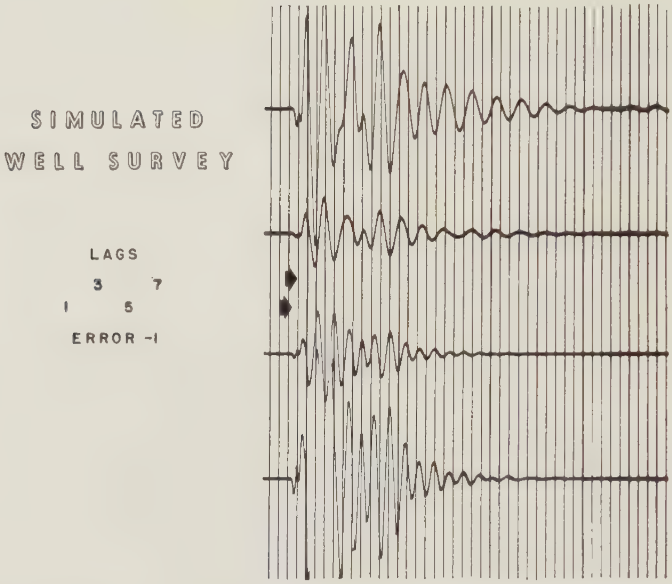

Fig. 3. Two closely spaced pulses (black arrows) applied in the simulated survey. Phase lag system recovers initiation time of second impulse with an error of one millisecond.

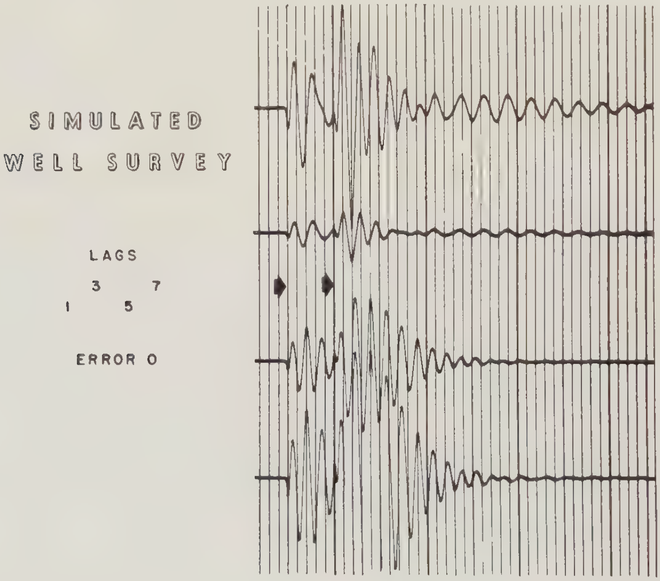

Fig. 4. Two widely spaced (52 ms.) pulses with the second pulse at twice the amplitude of the first. Phase lag system times second pulse correctly.

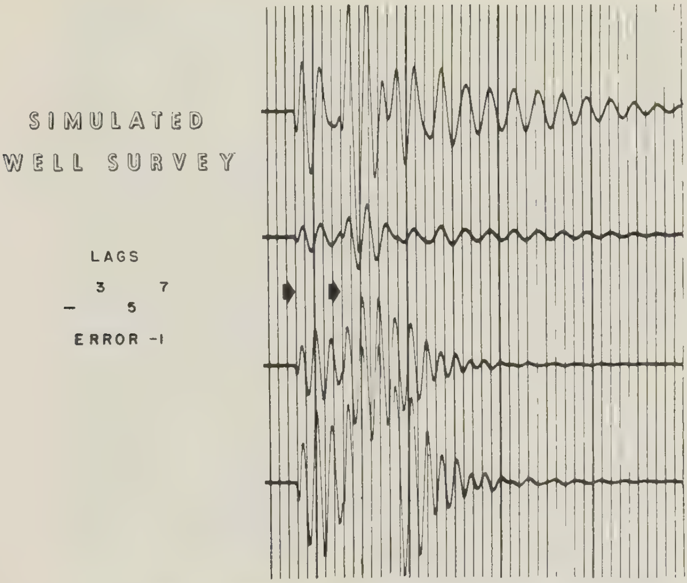

Fig. 5. Widely spaced (50 ms.) pulses with same amplitude ratio but slightly different phase relationship than in Figure 4. Phase lag system gives one millisecond error in timing second pulse.

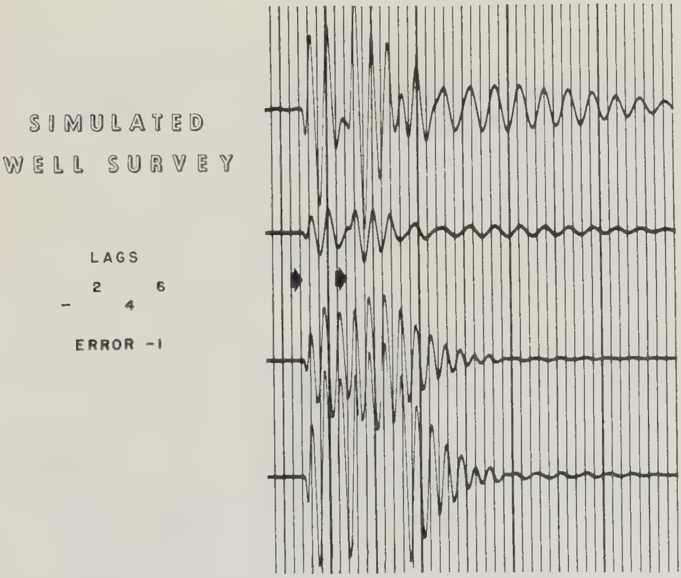

Fig. 6. Widely spaced (49 ms.) pulses of equal amplitude. Note the degree to which the second pulse is concealed on the bottom two traces. The phase lag system nevertheless recovers the second pulse time with a one millisecond error.

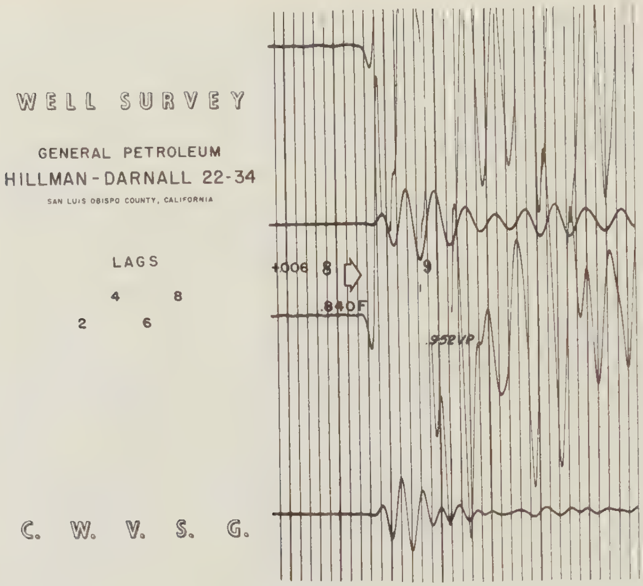

Fig. 7. Well survey record in which the formation break (indicated by arrow) is the first break. The time differences between the formation break and the various troughs and peaks were determined from reliable records such as this. These time differences increased somewhat with depth.

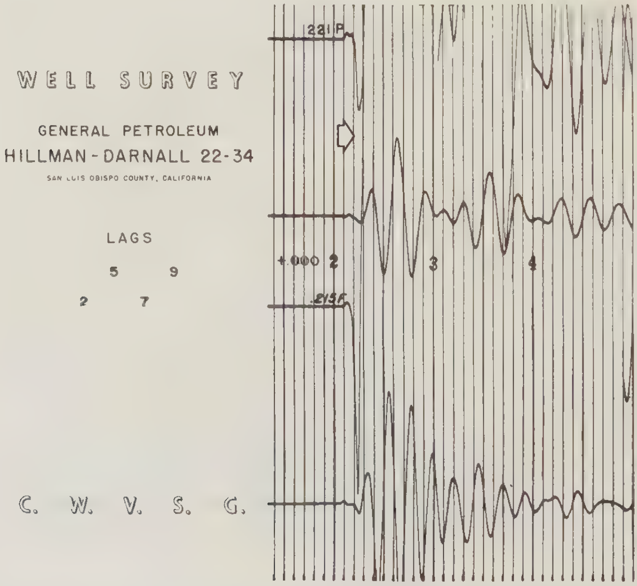

Fig. 8. Well survey record in which the formation break (arrow) occurs 5 ms. after a cable break.

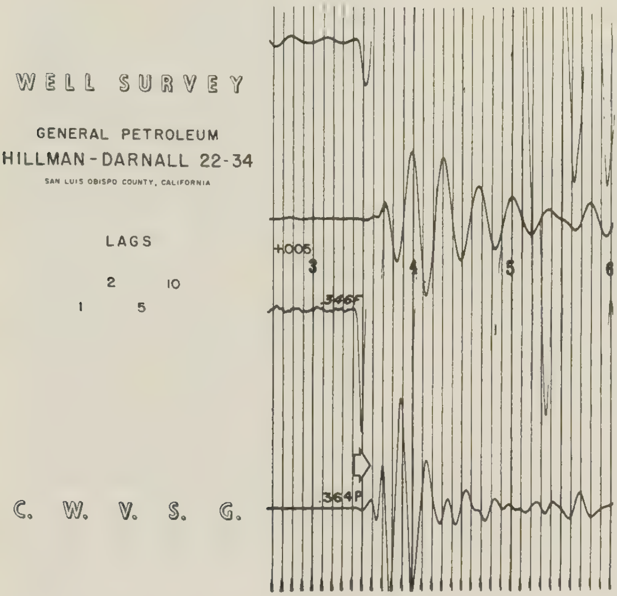

Fig. 9. Cable break preceding formation break by 18 ms.

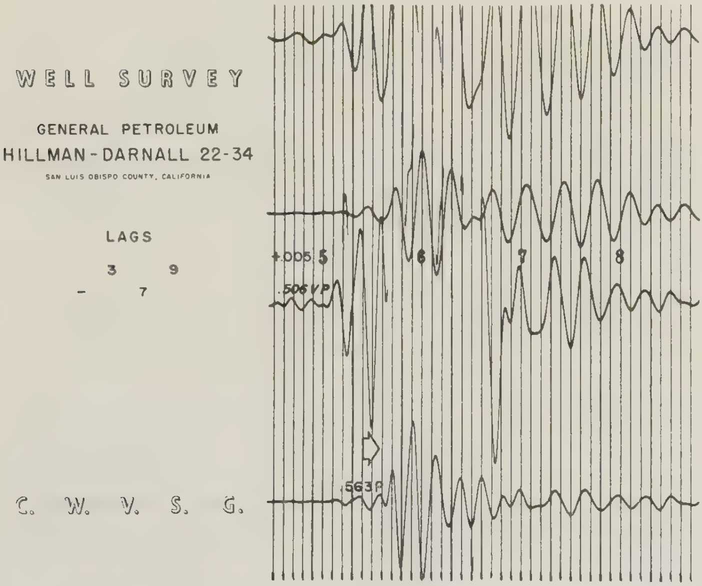

Fig. 10. Cable break 57 ms. ahead of formation break.

an accuracy of one or two milliseconds may reasonably be expected as is shown by the examples. Figures 3, 4, 5 and 6 illustrate the phase lag principle

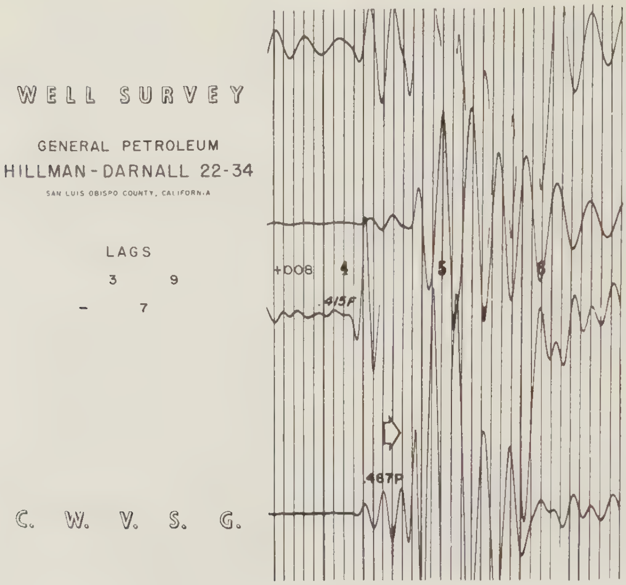

Fig. 11. Cable break 52 ms. ahead of formation break.

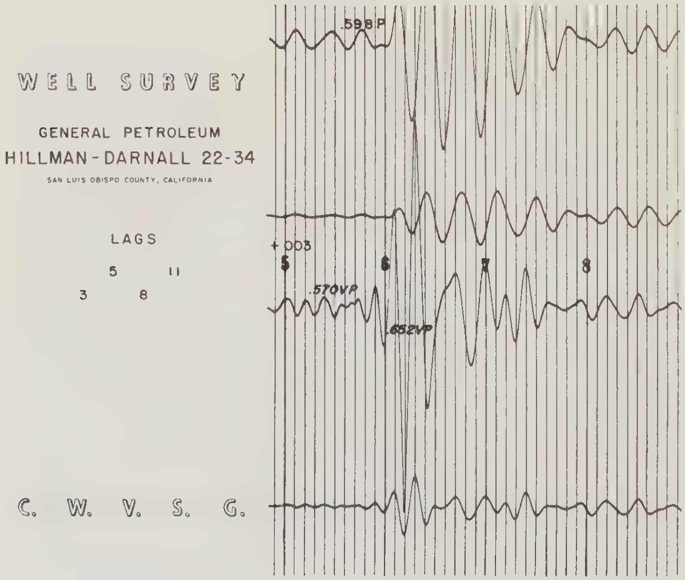

Fig. 12. Cable breaks 28 ms. ahead of and 54 ms. after formation break.

as obtained in laboratory tests using interfering pulses. In Figures 2 to 12, the top two traces are recorded through one filter, the bottom two through another.

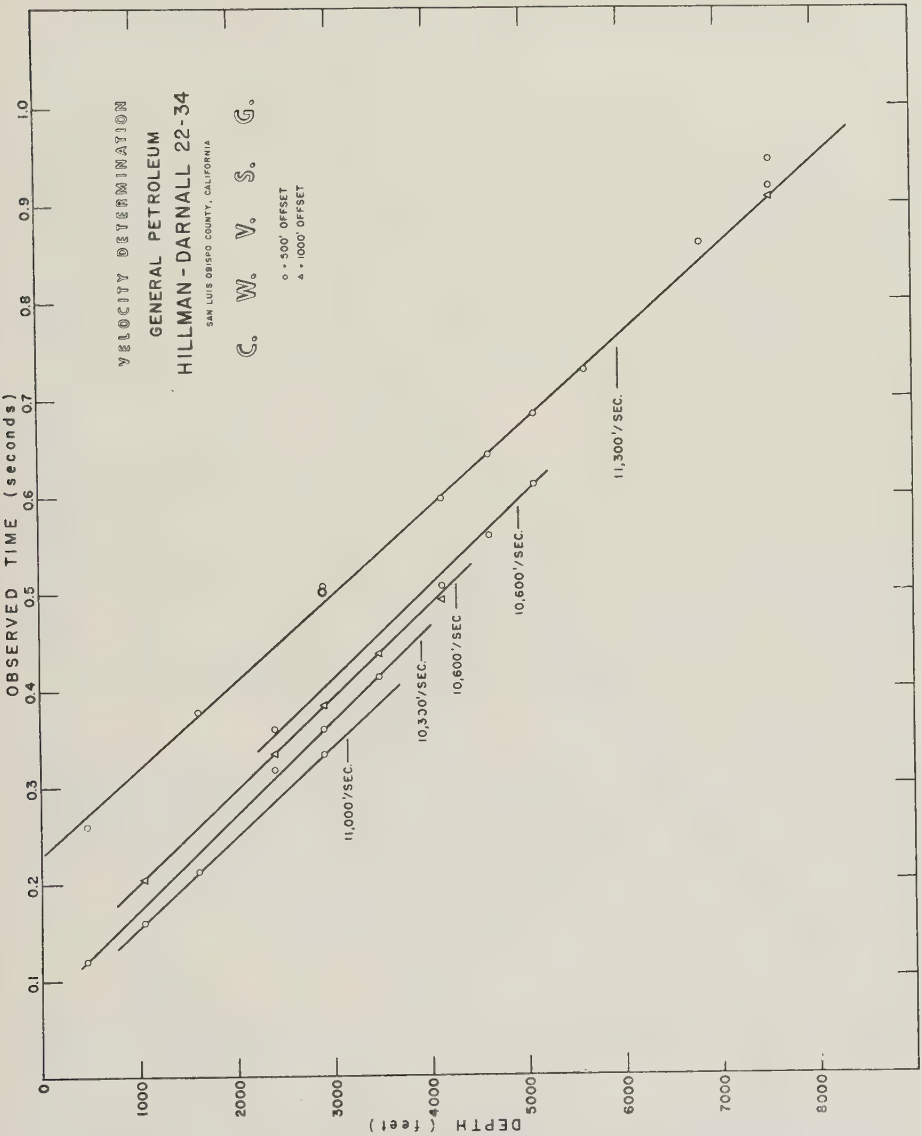

Fig. 13. Plot of observed (slant) times vs. vertical depth for cable breaks only.

Since the spectrum of the incoming pulse affects the period of the output pulses, the periods used to determine the actual impulse time are usually derived empirically. In general, the times obtained using the two different filters are averaged. The periods are also assumed to increase with increasing depth of the well seismometer.

The two filters must be chosen with response peaks sufficiently separated

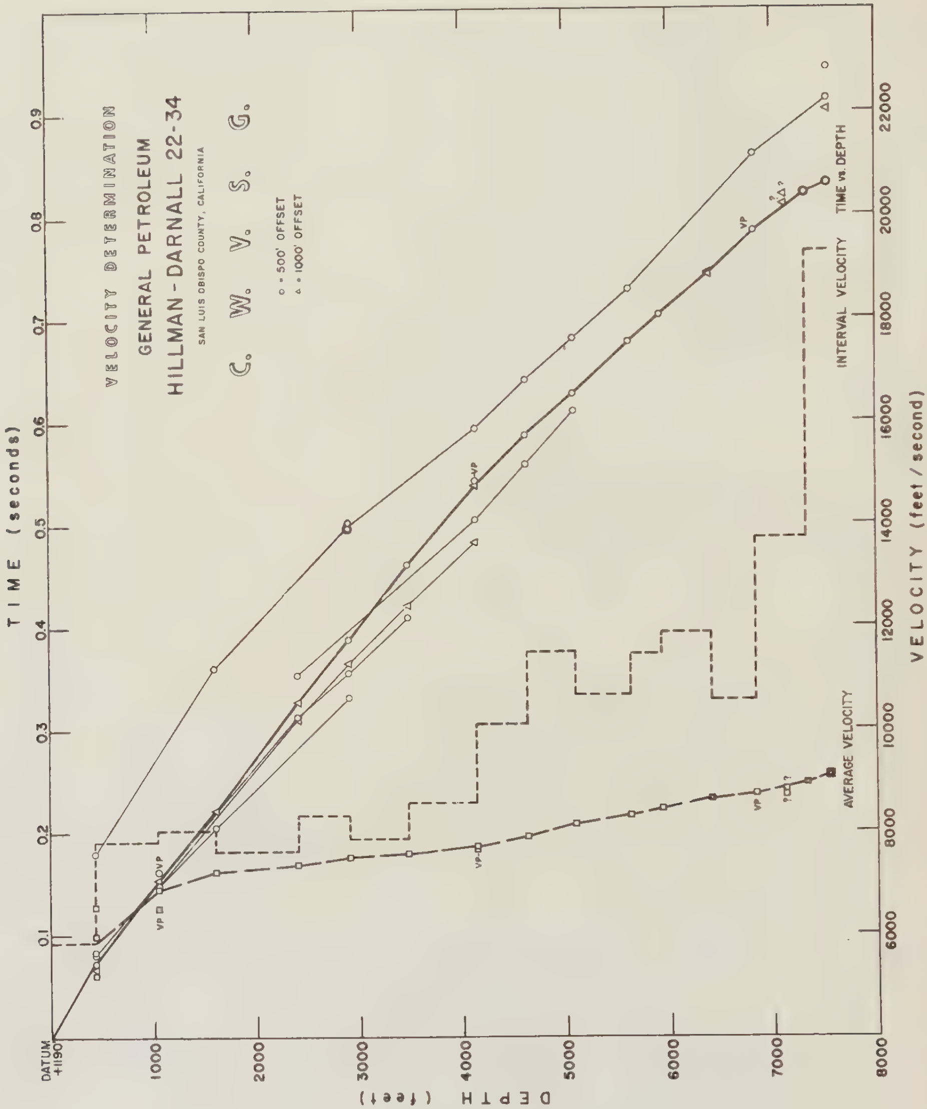

Fig. 14. Final interpretation of velocity survey with "cable break" systems shown by thin lines.

to produce considerable phase lag and thus eliminate the possibility of an error amounting to a full cycle. On the other hand, excessive separation may render the correspondence of peak-to-peak and trough-to-trough uncertain and may interfere with the proper recognition of individual pulses. In addition, of course, the filters must both be peaked within the range of usable seismic energy.

Incidentally, this method may be successfully applied to the determination of initial arrival times of reflections in ordinary reflection shooting.

After all possible arrivals on the records have been picked, it remains to segregate the "formation" arrivals. Three criteria are employed in this determination. First, the energy pulse with the greatest amplitude on a given record is normally the formation arrival since the attenuation on the extraneous paths is usually larger than on the "direct" path. Second, since the known velocity of impulses in the Schlumberger cable is of the order of 11,000 feet per second, any alignment of picks at or near this velocity on an observed time vs. depth plot must be looked upon with suspicion. Third, if shots are taken at two different offsets from the well and the picks from both offsets are computed by the standard routine, only "formation" picks will yield consistency in *vertical* time.

With these criteria it is possible to achieve a reliable report even in extreme cases such as the example presented here in which as many as four arrivals appeared on some records. The example is presented in Figures 7 to 14. Figures 7 to 12 are the actual well seismograms in which the "formation" picks are shown in vertical lettering and the "cable" picks are shown in slant lettering. Figure 13 is the observed time vs. depth plot for "cable breaks" in the survey and Figure 14 is the final result plot of the survey.

ACKNOWLEDGMENT

The authors wish to express their thanks to the General Petroleum Corporation for its cooperation in permitting the publication of the well velocity survey in this paper.

ABSTRACTS OF PAPERS PRESENTED AT THE ELEVENTH MEETING OF THE EUROPEAN ASSOCIATION OF EXPLORATION GEOPHYSICISTS, HELD IN MILAN, 12—14 DECEMBER 1956

J. T. Whetton, J. O. Myers and R. Smith, *Correlation of Rock Density Determinations for Gravity Survey Interpretation.*

Published in full length in the present issue of Geophysical Prospecting.

M. Caputo, *On the Behaviour of Worden Gravity Meters Used by the Italian Karakorum Expedition* (1954/55) *for Periodical Variations in External Temperature, and Rapid Variations of Pressure.*

A Worden gravity meter has been placed under conditions of sinusoidal variations of external temperature, with the aim to determine simultaneously the corresponding variations of temperature in the interior of the Dewar vacuum bottle, and the variations in readings. With the same aim a second Worden gravity meter has been placed under conditions of rapid variation of external pressure.

E. Hoge, *About some Magnetic Anomalies in Belgium.*

The author presents an unpublished chart of the vertical intensities of the earth's magnetic field, established for the South-Eastern part of Belgium. This chart brings into evidence a large regional anomaly covering all of the Ardennen, and more local anomalies where metamorphic rocks are present (Hautes-Fagnes and region of Paliseul, Libramont and Bastogne). More detailed surveys have been undertaken in these regions and the author discusses the connexion between magnetic anomalies and geology.

V. Baranov and J. Tassencourt, *Construction of Seismic Depth Sections with the Help of Electronic Computers.*

Most frequently, the depths and off-sets of seismic reflectors are calculated with the hypothesis that the propagation velocity varies linearly with respect to the depth. For a more complex velocity law, for example when the velocity law is given experimentally by a continuous velocity log, the calculations become too difficult. Furthermore, the possibility of a lateral change of the velocity should be taken into account. These problems can be easily and rapidly solved with electronic computers having magnetic drums. After reviewing briefly the theory and the general formulas, the following problems are studied: construction of charts for any velocity law; plotting of depth sections for the above velocity law; exact solution of the same problem when one can draw a "phantom horizon" on the time section. A logical chart is established for each of the above problems. Of course, the coding will depend on the type of computer used.

P. Gros and Y. Ledoux, *Méthodes actuelles d'interprétion en sismique réfraction.*

After er short historical review of the evolution of ideas concerning the technique and utilization of refraction shooting, the authors make a comparative analysis of the different methods actually used. Directing their attention especially to the several ways of considering the problem of interpretation, they insist on the possibilities offered by Gardner's method. The restrictions limiting the application of this process to well definited cases (small dips, uniformity of velocities) have been partially removed by means of certain modifications; several recent examples are supplied to support this theory, that contributes to enlarge appreciably the field of applications of the refraction shooting method.

C. Contini, C. Maino and M. Ranucci, *New Criteria for Interpreting Seismic Refraction Data.*

The principles and techniques gained from recent experience in seismic refraction prospecting, are discussed, in particular the execution of surveys, the picking of seismograms, the reduction of observed values, the principles for geological interpretation, plane layers with constant velocity and bending strata with constant velocity. Only strata with constant wave velocity are considered.

L. W. Erath, *Direct Recording VS. FM Recording in Seismic Tape Machines.*

This paper describes the two methods of magnetic tape recording used today in the seismic industry. It discusses objectively the characteristics of both methods including historical material, discussion of circuitry, magnetic tape, drive systems, effects of flutter and harmonic distortion, signal transfer and tape transport construction. The paper also includes discussion of noise and reproduction of transient signals. Diagrams illustrating the two recording systems, their frequency response and phase shift characteristics, distortion and noise levels as well as typical wave forms, are also attached.

G. Dohr, *Zur reflexionsseismischer Erfassung sehr tiefer Unstetigkeitsflächen.*

Referring to Schulz who placed very deep reflections—recorded in the Nahe-Senke area—into the contact zone between diorite and Gabbro (Konrad discontinuity), a study was undertaken of similar very deep reflections found during normal reflection seismic surveys in the foreland of the Schwarzwald (reflection times from 6,5 to 8,0 seconds) and in the Murnau (Oberbayern) area (reflection times from 6,5 and 11,0 seconds). The following observations show that these very deep events are not multiple reflections: the different bedding conditions between the reflectors in the upper zone and the very deep ones; the absence of any correlation between very deep and upper reflections; and the presence, in areas of tectonically deformed strata, of an almost horizontally boundary plane lying at a great depth. In the Murnau area planes of discontinuity were ascertained down to 18 and 30 km with an error probably not greater than 10%. The plane lying at a depth of 30 km was identified with the Mohorovicic layer.

F. Quarta and C. Maino, *Some Considerations on Well Velocity Surveys Carried out in Italy by AGIP Mineraria with Particular Reference to the Po Valley.*

The numerous well velocity measurements carried out in Italy by AGIP Mineraria are considered, in an attempt to establish some correlations between the determined velocities and the stratigraphic and lithologic characteristics of the terrains on which the measurements were made. The distribution of the seismic velocity is especially discussed in relation to depth, age and lithologic composition of the Tertiary formations in the Po Valley. Finally, mention is made of some satisfactory results newly obtained on the basis of such considerations, particularly for the definition of stratigraphic traps.

P. Dunoyer, *Réfraction des ondes sismiques dans les milieux anisotropes. Application aux mesures d'anisotropie dans un sondage au Sahara et à l'interprétation de la sismique-réfraction.*

The correct interpretation of refraction seismic data requires the knowledge of velocities along oblique raypaths, therefore the knowledge of the anisotropy factor. The anisotropy is assumed to be elliptical. From that hypothesis, the relationship between angles of refraction at an interface is derived.

Considering a borehole in which formations of different velocities and anisotropy factors occur, it is shown how the anisotropy factors for successive layers may be determined by means of radial well surveys, with the seismometer located at the interfaces between the layers. Experiments are described, which were carried out recently in a borehole in the Northern Sahara. The anisotropy of four layers, extending from the surface down to 2264 m, has thus been evaluated.

The influence of anisotropy on the relationship between delay-time and depth as well as between delay-time and offset is then studied. This influence appears to be considerable.

H. MEDER, *Reflected Refraction Waves on a Fault.*

The existence and interpretation of reflected refraction waves have been known for quite a time. This paper deals with the case of reflected refraction waves at non-horizontal key-horizons.

The paper also describes by a method for determining the position of the fault, by which the refraction waves are reflected, by means of a known key-horizon. This method is illustrated by an example.

A. ROMAGNA MANOJA, *Distribution of Seismic Energy in Stratified Media.*

"Starting from plane strata, a comparison has been made of the values of seismic energy according to geometrical optics, and of the values resulting from recent experiments and analytical considerations. The curvilinear behavior of seismic rays in case the energy transmission does not follow geometrical optics, has been investigated. The value of the intensity of seismic energy when the boundary surface is bended at some distance from the shot-point, is not equal to the value computed when assuming plane strata. The difference depends upon the amount of bending of the boundary relative to the wavelengths of the seismic waves. In these conditions long waves are refracted with higher energy than short waves. The reduction in the consumption of explosives, obtained by utilizing long waves, is pointed out.

E. BENEO and R. CASSINIS, *The Bottom of the Strait of Messina—Geological and Geophycial Studies.*

In the Fall of 1955, a geological and geophysical survey was carried out along the coasts and offshore in the Strait of Messina. The purpose of the exploration was to ascertain the possibity of realizing a bridge between the Island of Sicily and the continent. To this end it was desirable to determine the lithological composition of the shallow materials as well as that of the underlying metamorphic basement, to measure the thickness of the sedimentary formations both below the shores and below the channel's bottom, and to outline the buried tectonic features and the morphology of the metamorphic basement. The geophysical exploration comprised refraction and reflection seismic and resistivity. By the seismic method the thickness of the upper formations was measured and the morphology of the bedrock was outlined. With the help of both the resistivity and velocity measurements it was possible to obtain the lithological data of the formations by the comparison of the two physical parameters.

H. L. BREWER, *Reflection Seismograph Work in Southwest France Leading to the Discovery of the Parentis and Mothes Oil Fields.*

Geophysical methods are needed to detect, outline and detail the structures within the exploration permit of the Esso REP in southwest France. The Reflection Seismograph has been found to be the most reliable method to outline and detail the structures. The use of the reflection seismograph in this area is made difficult due to the thick surface sands, a high level of ground unrest, random interferences and a complicated subsurface. These difficulties were overcome by the use of a star pattern of geophones. This method gave good shallow and deep reflections in the Greater Parentis area and showed the presence of the Parentis and Mothes anticlinal trend which was found to be oil bearing when tested by the drill. Parentis is the largest oil field in Europe outside of the Iron Curtain. It is felt that Parentis and Mothes would not have been found without the use of pattern geophones.

E. CARABELLI and R. FOLICALDI, *Seismic Model Experiments on Thin Layers.*

Seismic two-dimensional model experiments have been carried out at the Laboratory of Fondazione Lerici in the Polytechnic School of Milan. The equipment used included pulse generators, piezoelectric transducers and amplifiers for detecting the waves propagated through the models. The experiments dealt with reflections from horizontal layers, thin in relation to the wavelengths. The thicknesses of the layers ranged from 1/50 to a few wavelengths. These strata consisted sometimes of materials having a lower, and sometimes of materials having a higher velocity than the surrounding medium.

The purpose of this research is to clarify the effects of very thin single or multiple reflecting layers on the reflection arrivals and to determine the influence of the thickness of the layers on the reflection energy. We are also studying for what minimum distance, in relation to the wavelength, the reflections from the reflecting horizons appear as separate events on the seismogram.

M. MATSCHINSKI, *Quelques problèmes de la prospection géochimique.*

Chemical cinematics provides a basis for interpretation of geochemical observations, by which the observed values of the contents of chemical elements may be extrapolated and information regarding the position and depth of an ore body may be obtained. Calculations are given of the form of the "congealed flame" which is provoked by the continuously displaced chemical reactions in the earth's crust. Such reactions which move from place to place in the earth's crust and their applications to practical problems of the geochemical prospecting are the subject of this communication.

H. RICHARD, *Purpose of Accident Reports and Statistics.*

Published in full length in the present issue of Geophysical Prospecting.

J. J. BREUSSE, *Application of Geophysical Prospecting to a Civil Engineering Problem. Hydroelectric Development of the Rhone Valley.*

Electrical prospecting with its particular technique of electrical sounding, and the shallow depth seismic refraction method, have been very helpful to solve the main basic problems connected with the great development projects of the Rhone Valley. The main problems dealt with are: the search for a convenient bedrock for hydro-electric plants and sluice gates; the laying out of head and tail races; and the study of alluvial water bearing layers and the effect produced upon them by opening the tail races.

E. WELIN, *Seismic Refraction Survey of a Hydro-electric Plant Site in Northern Sweden.*

The seismic method for determining the bedrock depth has had during the last ten years an ever increasing application in Sweden, especially as a reconnaissance method for planning hydro-electric projects. This paper describes a survey carried out for a projected power plant in Northern Sweden. Three alternatives for tunnel lines and dam sites were surveyed, by the seismic method, the total length of profile investigated comprising 16 km. Some twenty drill holes were then brought down through the glacial drift (depths down to 19 m) and drilled into the bedrock, affording a good confirmation of the results of the seismic work. The cost of the power station amounts to 12 million dollars of which only 12.000 dollars (0.1%) for seismic investigation. Through this comparatively small expenditure of time and money it was possible to choose an optimum alternative for tunnel line and dam site.

G. TØRNQVIST, *Geophysical History of the Iron-mine at Forsbo, Sweden.*

The paper gives an example of a prospection for an iron ore body in Sweden. High grade deposits of magnetite ore have been known for a long time within the leptite formation near Forsbo, but the mining has been very restricted on account of the small size of the ore bodies. A new magnetic ground survey disclosed a weak but extensive anomaly on the side of the known zone, which could be interpreted as being due to a magnetic body of a sizeable width at about 100 m depth. Drilling was recommended and a well workable deposit was found. In 1955, mining work has proceeded so far, that a comparison between the interpretation of the magnetic data and the ore reserves can be attempted. A short description of the procedures for determining the extent in depth of magnetic bodies and a diagram showing the influence of topography on magnetic measurements are also included in the paper.

An electromagnetic survey was carried out within the same area and the type of indication obtained over magnetite ore is shown.

L. ALFANO, *On the Influence of Lateral Variation of Resistivity on Electrical Prospecting.*

The object of this theoretical paper is to contribute to the improvement of the interpretative technique relative to vertical electrical sounding. The possibilities of calculating theoretical diagrams have been studied for the case where planes of discontinuity in electrical resistivity parallel and normal to the ground surface occur simultaneously. Many geological configurations of practical interest are contained in the present investigation, i.e. the case of a fault or that of a sharp interruption of a layer. It is shown that, when the electrical resistivity values of the different sections satisfy certain special conditions, the computation becomes very simple and does not differ excessively from that of a horizontal set of layers. The solution for the most general values of resistivities was also derived, but it presents greater difficulties.

V. FRITSCH, *Geoelectrical Measurements of the Atterberg-Limits of the Subsoil.*

The determination of the Atterberg-limits is of great importance for soil mechanics. Methods applied until now are complicated and necessitate the extraction of soil specimens. In many cases, as for instance in road-building, it is of advantage to calculate these items quickly in the field by means of simple measurements. A method is discussed which was developped by the author by order of the town authorities of Vienna for the measurement of roads. By means of geoelectrical measurements the specific resistance of the subsoil under the road surface may be obtained and from this the position of the Atterberg-limits and further the stability of the subsoil can be calculated.

E. BUDDE, *Radon Measurements as a Geophysical Measuring Method.*

Faults or uranium-bearing veins are often traceable through a layer of porous material even in some distance by measuring the Rn-contents of the ground air. It is shown by field measurements and laboratory tests that this distance depends on the character of the porous material (composition of the grain sizes and water content). A quantitative relation between the distribution of the grain size and the diffusion coefficient of radon is achieved by comparing the practical results with theoretical considerations.

P. VITTOZZI and A. DE MAIO, *Comparison between Measurements of Water Radio Activity by Two Different Methods.*

The measurements of water radioactivity of several thermal springs of Ischia Island, performed by two different methods, that of Aliverti-Lovera and that of Schmidt (Instituto Universitario Navale, Napoli), are compared. The conclusion is reached that, presumably, there are in the second of these methods causes of errors for which the ratio of radio-activities measured by the two methods appears to be a linear function (with constant $\neq 0$) of the time interval, during which water is contained in the bottles joined to the Schmidt's apparatus.

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

1. *Exploration History of the Block* 12 *Area, Andrews County, Texas.*
J. H. Deming & L. O. Dailey, Jr., A paper read at the Annual Meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published).

A general review of the geophysical history of the Block 12 area, Andrews County, Texas. Successive torsion-balance, gravimetric and seismic maps are presented and discussed. Subsurface geologic mapping and a geologic cross-section based upon well control are also presented with a summary of the generalised stratigraphy.

2. *Good Hope Field, St. Charles Parish, Louisiana — A Geophysical Case History.*
G. A. Burton, A paper read at the Annual Meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published).

Gravity and seismic reflection methods were used to find this oilfield which is suspected to lie over a deep-seated salt dome.

3. *Geophysical Case History, Parentis Oil Field, France.*
R. Vajk & Walton, Geophysics, Vol. XXI, No. 3, pp. 815.

A gravity survey and a subsequent seismic reflection survey are credited with the discovery of this oilfield which is the most important in Europe outside the iron curtain. Gravity, seismic, telluric and geological maps and profiles are presented.

4. *The Phenomenon of Fluctuations in Geophysics. Their Mathematical Description and their Practical Application.* (In Italian).
M. Matschinski, R.C. Acad. Naz. Lincei, Vol. 18, No. 4, pp. 378-385, April, 1955.

The description of fluctuation by ellipses or ellipsoids, instead of circles or spheres, is developed using the principle of transposition. It is shown that the fluctuations of a field potential, determined by the tensor-means, are a double gradient of a scalar super potential Φ, which resolves the equation $\Delta\Phi = 0$. This superpotential is the potential of the fluctuations. This fact is held to be very useful for problems concerning gravitic and electromagnetic fields, mineral prospecting, etc., and permits use of measurements of the fluctuations of the primary derivatives (of one point) rather than those of the secondary derivatives (of two adjacent points).

(From Physics Abstracts, A, November 1955)

5. *Crossroads of Geophysics.*
P. L. Lyons, Geophysics, Vol. 21, No. 1, pp. 1-15, January 1956.

The use of geophysics in the U.S.A. has found, over the last 25 years, 22,500,000,000 barrels of oil and 134 trillion cubic feet of natural gas. These figures represent between one half and one third of the total discoveries during the same period. Geophysics, in this time, has accelerated tremendously to its present maturity, but it now faces an economic crossroads.

In an attempt to illuminate the future of geophysics, the author has made an intense study of its growth in the U.S.A. over the last 25 years. His findings are illustrated by numerous graphs and maps.

6. *Review of Current Developments in Exploration Geophysics.*
M. B. Dobrin & R. G. Van Nostrand, Geophysics, Vol. 21, No. 1, pp. 142-155, January 1956.

The most notable of recent advances in geophysics are magnetic recording and velocity logging. Magnetic recording permits greater flexibility in seismic interpretation and automatic time correction, facilitates compositing and preparation of record sections and offers a form of storage for seismic data suitable for any subsequent processing. Interval velocity logging provides a better understanding of reflections from sections of complex layering, thus improving reflection interpretation technique.

Other recent advances in seismic prospecting include new ways of generating seismic energy and the use of high-frequency techniques.

Important advances have not been confined to the seismic field. The gamma-gamma logger now gives density data accurate enough for gravity interpretation; the induced polarization method has proved successful in finding ground water; airborne electromagnetic methods have been used widely in Canada for finding base metals; and a new airborne nuclear-magnetic-resonance magnetometer is in service.

7. *There's Oil Under Those Shelves.*
H. C. Cortes & R. N. Gsell, Oil & Gas J., Vol. 54, No. 22, pp. 103-107, October 3, 1955.

Geophysical prospecting is finding structures favourable for drilling over various shelf areas off North and South America. A short account is given of the gravity, seismic reflection and seismic refraction methods used.

8. *Study of Relationship Between Safety Effort and Accident Rate.*
W. H. Hawkes, Geophysics, Vol. 20, No. 3, p. 717, July 1955.
(Abstract only of paper read at the 10th Annual Gulf Coast Meeting of the S.E.G. at San Antonio, Texas, May 1955).

A resumé of a survey conducted during 1954 among geophysical contractors and shot-hole drilling contractors. The results were classified, tabulated and analysed from the standpoint of effectiveness of the committee's safety efforts and some important conclusions were reached regarding the committee's future course of action. Some revealing correlations are drawn between the safety effort expended and safety results obtained.

9. *Geophysics—An Aid in Coal Mining.*
E. J. Polak, Colliery Engineering, August 1955.

This paper discusses the various coal mining problems that are investigated by geophysics and suggests the appropriate geophysical method for each problem. To illustrate the discussion, examples are taken from the Cannock Chase coalfield. The value of geophysics is stressed in the part it plays concerning safe working in the coal industry.

10. *Geophysics and Geochemistry Move Ahead in* 1954.
H. M. Mooney, Mining Engineering, Vol. 7, No. 3, pp. 251-256, 1955.

During 1954 there was a significant trend toward increased use of electromagnetic and geochemical methods of exploration. Airborne scintillometer and magnetic methods have become a routine combination. Ground magnetic and gravity surveys continued to play an important role in geologic studies. The use of resistivity methods has shown a moderate increase. The application of seismic exploration was extended. The most promising instrumental developments were airborne electromagnetic equipment, a magnetometer based on nuclear resonance, and reflection seismic equipment operable at depths of less than 100 feet. Important theoretical and experimental research was conducted in the improvement of established methods of exploration and in the development of new methods.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

11. *The Role of Geophysical Methods in Modern Exploration Programmes.*
A. A. Brant, Eng. Min. J., Vol. 156, No. 3a, pp. 25-32, 1955.

A discussion on the role of geophysics in mining exploration programmes, including the uses and limitations of each of the geophysical methods employed in exploration for metals.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

12. *Investigating Ground Water by Applied Geophysics.*
D. K. Todd, Am. Soc. Civil Engineers Proc., Vol. 81, Separate No. 625, 1955.

The basic principles of and information provided by resistivity, seismic-refraction and electrical-logging methods, particularly in their application to problems of ground-water exploration, are briefly described. A bibliography of 66 English-language items is included.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

13. *Application of Geophysical Methods to Prospecting for Ground Water.* (In Spanish).
J. Cantos, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 9, Fasc. 9, pp. 163-189, 1954.

A resumé of electrical, gravimetric and seismic prospecting for water, in Spain, by the geophysical section of the Institute of Geology and Minerals.

14. *U.S. Geophysical Activity Starts Upward Push.*
J. E. Kastrop, Petroleum Engineer, Vol. 27, No. 10, pp. B. 35-37, September. 1955.

For the first time in nearly a year, geophysical activity in the U.S.A. is reported to be on the increase. By the end of April 1955 nearly 40 more crews were in the field than at the end of December 1954. Much of the increase is due to more extensive exploration in Texas and southern Louisiana.

15. *Why Was My Well Dry?*
Oil & Gas J., Vol. 54, No. 28, pp. 148-151, November 14, 1955.

This article gives a check list of factors (with short notes on each) that should be considered before drilling a well, to ensure that the location by geophysical and other methods is correct.

16. *European Association of Exploration Geophysicists-Meeting in London.*
L. H. Tarrant, Nature, Vol. 177, No. 4499, pp. 120-121, January 21, 1956.

At the 9th meeting of the E.A.E.G. held in London during 7-9th December 1955, twenty seven papers were read.

R. G. Van Nostrand and M. B. Dobrin read a paper on current U.S. developments in exploration geophysics. G. Phillips and G. S. Waters gave detail of a new magnetometer which is specially adaptable for use in light aircraft. C. H. Johnson presented a paper on high frequency reflection systems. N. A. Anstey spoke on instrumental distortion and the seismic record.

Of the remaining papers, almost half dealt with the detailed mathematical and geometrical problems of geophysical interpretations. Papers by F. Vehretout, M. Rimbaut and by J. Schoeffler and L. N. Nardon were concerned with seismic reflection problems; those by L. H. Tarrant and by S. Wyrobek dealt with refraction interpretation; those by A. H. Kleijn and by K. Helbig investigated the effects of seismic anisotropy; while A. Lundbak, C. Monnet, A. Hahn and T. Knight gave papers on gravity and/or magnetic interpretation.

Results of gravity determinations were contained in papers by F. A. Vening Meinesz and A. P. Collette, by G. P. Woolard, W. E. Bonini and J. C. Rose and by J. C. Rose and G. P. Woolard.

Seismic field research was the subject of papers by T. F. Gaskell, M. Pieuchet and H. Richard and by R. G. Mason.

Actual field surveys for minerals were described by M. Guerrier and A. Rogier and by R. Cassinis.

In the remaining papers, W. Domzalski dealt with problems of very shallow refraction work; F. Sumi discussed some of the refinements of the electrical earth-resistivity method; M. Matschinski presented some novel ideas on the possible turning to advantage of seismic noise in prospecting; and O. Meisser described very precise hydrostatic levelling for foundation problems.

17. *Why Some Geologists and Geophysicists Don't Mix.*

M. T. Haltbouty, Oil & Gas J., Vol. 54, No. 36, pp. 148-151, January 9, 1956.

The author, a working geologist, traces briefly the history of the petroleum geology and geophysical professions, and stresses their lack of co-operation throughout. He puts blame on the management whose duty it was to co-ordinate the activities of the two professions and ensure that they developed together. He then outlines twelve steps that should be taken to enable the two to join forces and work together to their mutual advantage.

18. *Geophysical Outlook.*

H. C. McCarver, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March 1956. (Not yet published).

A thought provoking article for all persons engaged in petroleum exploration. Advances are called for in the economics, personnel, instrumentation and application. Results must improve or there is a danger of being priced out of the business.

19. *Geological and Geophysical Exploration in Yugoslav Petroleum Areas* 1945-55. (In Yugoslav).

F. Ozegovic, Nafta (Yugoslavia), Vol. 6, No. 8, pp. 243-249, 1955.

From 1945 to 1955, 7,236 sq. km. were explored with the gravimeter, 110 sq. km. with the torsion balance, 646 sq. km. with the magnetometer, and 797 sq. km. with the seismometer. Exploration work in Crotia, Slovenia and Bosnia was particularly intensive.

20. *Proceedings of the Washington Conference on Theoretical Geophysics* — 1956.

J. Geophys. Research, Vol. 61, No. 2, Part 2 (Special Conference Section), pp. 317-414, June 1956.

A Conference on theoretical geophysics was held at Washington in February, 1956, sponsored by the National Science Foundation and the Carnegie Institution of Washington. The Conference considered theoretical and mathematical approaches in the solution of geophysical problems, mainly in meteorology, oceanography, hydromagnetism, geomagnetism, aurora, cosmic rays, ionospheric physics, atmospheric electricity, geochemistry, seismology, gravity and geodesy, techtonophysics, and the origin of the earth. Its aims were to obtain a broad picture of the current status of knowledge of geophysics in the U.S.A. and abroad, to encourage increased activity in theoretical geophysics, and to discuss further programmes and opportunities.

This special section of the journal contains summaries and abstracts of the various contributions.

21. *State of Petroleum Geology and Geophysics.* (In German).
H. Closs & W. Schott, Erdöl u Kohle, Vol. 8, No. 6, pp. 367-372, 1955.
Developments in petroleum geology and applied geophysics in Germany are reviewed separately.

22. *Geophysics and Petroleum Exploration.* (In French).
L. Migaux, Rev. Inst. Francais du Petr., Vol. 10, No. 10, pp. 1191-1204, 1955.
A general review of gravity, magnetic, electrical and seismic methods of exploring for oil.

23. *Geophysics and its Applications.* (In Portuguese).
R. Martin, Brasil Univ., Escola de Minas Rev., Vol. 19, Nos. 2-6, pp. 3-9, 1954.
A brief review of methods of applied geophysics for the investigation of geological problems and the exploration of mineral deposits.

24. *Geophysics as an Aid in Coalmining.*
E. J. Polak, Colliery Eng., Vol. 32, No. 378, pp. 330-334, 1955.
A brief description of the magnetic, gravitational, electrical and seismic methods of exploration and their application to coal-mining.

SEISMIC — GENERAL

25. *British Seismology During* 1954-55.
E. Tillotson, Nature, Vol. 176, No. 4484, pp. 679-80, October 8, 1955.
This article is a very brief review of the 60th annual report of the Committee for Seismological Investigations appointed by the British Association, covering the work done by British seismologists during the year 1954-55, which was presented to Section A (Physics & Maths.) of the Association at its 1955 Bristol meeting. The highlights are as follows:

Dr. M. N. Hill continued his seismic refraction shooting experiments in the English Channel and the Western Approaches.

Dr. R. Stonely investigated the problem of the propagation of surface waves in a medium with cubic symmetry, the free surface of which is a principal plane.

E. F. Baxter, director of the Durham University Observatory, is building an underground seismograph chamber and is planning new instruments. He also investigated the Yorks. earth tremors of October 23, 1954.

J. Darbyshire, of the National Institute of Oceanography, has calculated refraction diagrams for microseismic waves approaching Bermuda.

In addition a very brief account of various international co-operative activities is given.

26. *Majeau Lake, Alberta—A Discovery Resulting from a Restudy of Seismic Data.*
H. R. Renden, A paper read at the Annual meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published).
The discovery of the Majeau Lake oil and gas field resulted from critical restudy of existing seismic records in an attempt to find the "Rundle pinchout" between two wells. Early development confirms the seismic interpretations but indicates the geology to be more complex than was originally thought.

27. *Alternative Modes of Seismogram Recording.*
F. S. Kramer & R. A. Peterson, A paper read at the Annual Meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published).
A short discussion is presented on the relationship between the data traces on the seismogram and correlative geologic features. Alternative modes of recording seismic data traces are then discussed, including various moving light spots, vari-

able density and coded flashing methods. Illustrative examples and comparisons are shown.

28. *On the Propagation of Seismic Impulses in the Malm Chalk Bed of the Swabia-Franconia Juras.* (In German).
H. Reich, Zeitschr. für Geophys., Vol. 20, No. 1, pp. 8-24, 1954.
An account of seismic refraction investigations in the region of the Malm chalk bed of the Swabia-Franconia Juras, where unusual stratification occurs.

29. *The Results of Seismic Reflection Investigations Made in the Rammelsberg Mountain and its Vicinity.* (In German).
E. Kraume, Zeitschr. Erzbergbau u. Metallhüttenwesen, Band 7, Heft 7, pp. 277-280, 1954.

30. *Seismic Prospecting on Kusano Plain at the Central Part of Joban Coal Field.* (In Japanese with English Resume).
T. Tateishi, Geol. Surv. Japan Bull., Vol. 5, No. 12, pp. 39-44, 1954.

31. *Seismic Prospecting on Tomioka District, Joban Coal Field.* (In Japanese with English Resume).
S. Ninagawa, Geol. Surv. Japan Bull., Vol. 5, No. 9, pp. 41-50, 1954.

32. *Seismograph Correlation between Permian Reef Line and Basintype Section, Hockley County, Texas.*
J. Daly, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March, 1956. (Not yet published).
This paper shows the seismograph as a tool useful in solving stratigraphic problems in the Permian Basin area. The correlation of the massive carbonate deposits of the barrier-reef line with the bedded clastics and carbonates of the basins is particularly difficult.

33. *Magnetic Tape Can Find More Oil.*
P. P. Gaby, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March, 1956. (Not yet published).
The advantages to be gained with magnetic tape may be broadly divided into:
1. Storing data to derive advantage from development of any technique.
2. Furthering present research.
3. Obtaining enough advantage and improvement to allow finding oil now that would not be found otherwise.
This paper deals with present use of magnetic tape, indicating several general types of case where substantial improvement is now available through, and only through, magnetic recording. Sample record-cross-sections are presented.

34. *Report on Continuous Velocity Logging.*
H. W. Lawrence, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March, 1956. (Not yet published).
Several types of velocity-logging tools are presently in use, some on an experimental basis and others commercially. Those types on which information has been released are briefly described.
Velocity logs have been run in over 750 wells, about half by oil companies using their own instruments and the other half by commercial contractors. Geographical distribution of the wells logged is wide. It includes Canada, Venezuela, France, England and the U.S.A.
Application of velocity logs, other than as a velocity tool, are increasing with the

corresponding increase in the number of wells logged. The correlation potential of the logs is immediately apparent. Recent experimental work and papers have pointed out velocity-porosity relationships and possibilities of determining fluid content.

35. *European Seismological Commission.*
Nature, Vol. 177, No. 4518, pp. 1021-1022, June 2, 1956.

A meeting of the European Seismological Commission was held during April 1956, in Vienna and the following topics were discussed:

(a) Large explosions, particularly in Alpine regions, for the purpose of seismic investigations of the earth's crust.

(b) Progress in the preparation of a European Earthquake Catalogue and a seismotectonic map of Europe.

(c) Progress in seismometer development.

(d) Microseisms.

36. *Team Work in Seismic Prospecting.*
G. Brinckmeier, Geophysical Prospecting, Vol. 4, No. 2, pp. 105-11, June 1956.

In his Presidential Address delivered at the 10th meeting of the E.A.E.G. at Hamburg, May 1956, G. Brinckmeier briefly relates the history of seismic prospecting from the beginning when it was a one-man science, to the present when a team of individual specialists is necessary. He then outlines the part played by each of the men involved in a modern seismic survey, emphasising the co-operation that must exist between them to attain the best results.

37. *Improvements in Seismic Prospecting.*
Nature, Vol. 177, No. 4522, pp. 1209-1210, June 30, 1956.

A geophysical discussion of the Royal Astronomical Society was held at Burlington House, London, on April 20, when three papers were read on "Improvements in Seismic Prospecting". Mr. B. C. Browne was in the chair.

The first paper, by F. W. Hales, dealt with the development and applications of continuous velocity logging. The second paper, by Dr. R. Rait, described the seismic refraction work that has been done in the equatorial Pacific Ocean on the Mid-Pacific and Capricorn Expeditions in 1950 and 1952-53, respectively. Some improvements have been made in the utilization of explosive energy for seismic waves and decreasing the noise picked up in the hydrophones. The third paper, by Dr. S. Wyrobek, describes a refraction interpretation method utilizing delay and intercept times.

38. *Rayleigh-Wave Dispersion and Crustal Structure in the East Atlantic Ocean Basin.*
H. Berckhemer, Bull. Seismol. Soc. Am., Vol. 46, No. 2, pp. 83-86, April, 1956.

Investigations of surface waves crossing the part of the Atlantic Ocean west of the Mid-Atlantic Ridge indicate a thin crustal layer overlying a higher-velocity ultrabasic material. East of the Ridge, indications are of a more continental crustal structure. In this investigation use is made of the dispersion of Rayleigh waves generated by earthquakes in the Mid-Atlantic Ridge. Observations were made at stations close to the East Atlantic shore.

SEISMIC — INSTRUMENTAL

39. *VLF Refraction Method with less Explosives Gives Excellent Results.*
J. A. F. Gerrard, World Oil, Vol. 141, No. 4, pp. 79-83, Sept. 1955.

A short general article describing the theory and development of the method of obtaining very low frequency refraction seismographs. The low frequency response and sensitivity are suited to great spread lengths; the charges employed are small, and the onset of the seismic event is clearly shown on the VLF record. A modern VLF unit, consisting of 12 amplifiers, power supply, input unit and detector are adequately portable.

40. *Patents.* Abstracts in Geophysics, Vol. 21, No. 1, p. 193, January, 1956.

U.S. 2, 713, 620.	19 July 1955.	A seismic A.V.C. system.
U.S. 2, 717, 369.	6 Sept. 1955.	A pressure-sensitive deep well seismic detector.
U.S. 2, 717, 821.	13 Sept. 1955.	A synchronous timing line motor.

41. *A Rational Approach to the Design of Electrical Filters and of Shot-Hole and Geophone Patterns in Seismic Reflection Prospecting.*

F. Muir & F. W. Hales, Geophysical Prospecting, Vol. 3, No. 4, pp. 350-358, December 1955.

The authors develop an optimum filtering theory for seismic reflection recording. A criterion of record improvement is applied to a mathematical model consisting of a set of wavelets superimposed on a random noise background. This leads to the design of electrical filters and geophone and shot-hole patterns with optimum filtering characteristics.

(Author's Abstract).

42. *New Techniques Being Used to Find Stratigraphic Traps.*

N. Clayton & R. A. Pohly, World Oil, Vol. 140, No. 5, pp. 116-118, April 1955.

Seismic and gravimetric methods are discussed. Two recent advances in seismic technique, though both originally developed for other purposes, should prove helpful. These are the magnetic tape recorder, and the high-resolution seismograph. It is shown how the latter may be used to produce isotime maps.

43. *Transitor Power Converter Capable of 250 Watts D.C. Output.*

G. C. Uchrin, Proc. I.R.E., Vol. 44, No. 2, pp. 261-2, February 1956.

The Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey have developed a transitor power converter capable of delivering 250 watts d.c. output from a nominal 24-volt d.c. input supply. The type of circuitry employed is that of the 'self-excited square-wave transitor power oscillator'. Two transformer designs have developed for the circuit; their performances are compared.

44. *Theory of Eden's Twin Strips and Application of it to Magnifying Mechanism of Seismometer.*

G. Nishimura, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 32, Pt. 1, pp. 86-111, 1954.

"Eden's twin strips" is a magnifying mechanism chiefly used for comparators of high sensitivity. It has been used in vibration measuring instruments including vibrographs, accelerographs, and vibration tables. The theory of the strips and the application in seismometry is developed in this paper.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

45. *Patents.* Abstracts in Geophysics, Vol. 20, No. 4, p. 948, October 1955.

U.S. 2, 706, 401.	19 April 1955.	A low-frequency seismometer with a mass suspended on two leaf springs such that translation produces a rotary motion.
U.S. 2, 706, 805.	19 April 1955.	A seismometer which utilizes emfs from eddy-current fields.
U.S. 2, 707, 524.	3 May 1955.	A seismic system for firing a shot coincident with a heavy timing line.
U.S. 2, 708, 742.	17 May 1955.	A hydrophone cable array having a central

		strain cable with transducers spaced along it with the conductors.
U.S. 2, 709, 206.	24 May 1955.	A seismograph constant time delay band-pass filter.
U.S. 2, 710, 070.	7 June 1955.	A seismic profiling method in which a desired number of traces are overlapped and a composite of variable-area records is photographed.
U.S. 2, 710, 661.	14 June 1955.	A method of compositing seismic records.

46. *A New Multi-Trace Oscilloscope.*
Electronic Engineering, Vol. 28, No. 335, pp. 38, January 1956.

A very brief description of a 24-trace cathode-ray oscilloscope for the direct presentation on a 21" tube of multichannel information. Information is presented by intensity modulation of a 5,000c/s raster, resulting in frequency response useful to 500c/s on all 24 traces with only a single electrongun. Each trace may cross over the others, and is limited in amplitude only by the size of the cathode ray tube. A position control is provided for each trace, and a special "window" control permits a portion of the sweep to be accelerated for detailed examination. An auxiliary unit, the Event Pre-Selector, puts 0.1 and 0.01 sec. timing lines over the scope, and triggers the sweep after an adjustable delay period following the initial pulse. This feature is especially useful when monitoring 24-channel magnetic tape recordings.

47. *Getting the Most Out of Present Seismic Instruments.*
J. E. Hawkins, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March, 1956. (Not yet published).

Much of the present seismic work is being carried out in areas where results are difficult to obtain. This paper outlines the requirements for seismic instruments for these operations. The particular characteristics desired for specific problems are illustrated, and the instrument factors that affect these characteristics are outlined. Examples of the effect of instrument adjustment are shown. Means of arriving at optimum results with present equipment under diversified field conditions in different areas are illustrated by specific cases.

48. *Evolution of Seismic Instruments.*
J. P. Woods, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March, 1956. (not yet published) .

Seismic prospecting is 30 years old. In this time, seismic instruments have changed greatly. The problems of prospecting are now difficult. To meet the increased difficulty, seismic instruments have been changed so that much more data is taken.

The approach has been statistical. The bad data is cancelled by various averaging processes. In the past, there have been several near-revolutions in the seismic method. Today it appears that great changes in instruments and methods may come from the introduction of magnetic recording, computing machines, correlation machines, and the generation of seismic waves by weight dropping. At present, it is hard to evaluate these possibilities.

49. *Patents.* Abstracts in Geophysics, Vol. 21, No. 2, p. 487, April, 1956.

U.S. 2, 724, 819.	22 Nov. 1955.	An electrostatic seismometer.
U.S. 2, 725, 527.	29 Nov. 1955.	A testing device for measuring amplifier phase shift.
U.S. 2, 725, 534.	29 Nov. 1955.	A seismograph channel which corrects the non-linear phase-frequency characteristic.
U.S. 2, 725, 548.	29 Nov. 1955.	A variable-capacitor pressure geophone.

U.S. 2, 725, 821.	6 Dec. 1955.	Seismic circuit closing means and blasting assembly.
U.S. 2, 725, 822.	6 Dec. 1955.	A switch and blasting method for seismic prospecting.
U.S. 2, 726, 131.	6 Dec. 1955.	Modulated galvanometer recording of transient signals.
U.S. 2, 726, 290.	6 Dec. 1955.	A surgeless electronic variable resistor and attenuator for an avc system.

50. *Patents*. Abstracts in Geophysics, Vol. 21, No. 3, p. 856, July, 1956.

U.S. 2, 729, 094.	3 Jan. 1956.	A geophone-testing device which drops a series of balls from a container above the geophone.
U.S. 2, 729, 300.	3 Jan. 1956.	An oil-filled detector streamer for water-borne seismic prospecting.
U.S. 2, 732, 025.	24 Jan. 1956.	A method and apparatus for analysis of seismic records, employing photo-electric compositing and pantographs.
U.S. 2, 732, 536.	24 Jan. 1956.	A pressure-sensitive cylindrical hydrophone.
U.S. 2, 733, 412.	31 Jan. 1956.	A system for eliminating highline pickup on seismic amplifiers.
U.S. 2, 739, 297.	20 Mar. 1956.	A low-frequency variable-capacity type seismometer.

51. *The Automatic Amplified Gain Control in Seismic Amplifiers*. (In Russian).
A. I. Slutskovski, Prikladnaya Geofiz., Vypusk 12, pp. 210-216, 1955.

SEISMIC — FIELD TECHNIQUE

52. *Patents*. Abstracts in Geophysics, Vol. 21, No. 1, p. 193, January 1956.

U.S. 2, 713, 395.	19 July 1955.	A shooting system using elevated charges in a pattern for accentuating refraction arrivals.
U.S. 2, 717, 656.	13 Sept. 1955.	A shot planting method in which the charge is dropped from a helicopter, and detonated.
U.S. 2, 718, 928.	27 Sept. 1955.	A method of locating the edge of a low-velocity layer by firing a shot in a well and placing detectors on the surface above the edge of the layer.
U.S. 2, 718, 929.	27 Sept. 1955.	A method of locating a high velocity body which intersects a low-velocity layer by placing both shot and detector in a well.
U.S. 2, 718, 930.	27 Sept. 1955.	A seismic method in which the shot and a spread of detectors are placed in a deep well and cross spreads of detectors are placed on the surface.

53. *Symposium—On Multiple Seismometers*.
F. van Melle, F. Reynolds, R. Palmer, K. Burg, & F. E. Romberg, A paper read at the Annual Meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published) .

The various aspects of multiple seismometer (and multiple shot) exploration are discussed. Each man gives his ideas as to the most important problems and pitfalls connected with such shooting. The economics of multiple shooting, the advantages to geologic understanding, the best methods of instrumentation, and the use of multiple shots and non-explosive energy, are treated.

SEISMIC — INTERPRETATION

54. *Protractor for the Rapid Construction of Refracted Rays*. (In French).
J. Schoeffler & E. Diemer, Geophysical Prospecting, Vol. 3, No. 3, pp. 234-239, September 1955.

A protactor is described which provides a very simple method of constructing refracted rays in a vertical plane. The apparatus is very simple and may easily be constructed in any computing office.

55. *Determination of the True Position of a Reflecting Horizon Located Under a Refracting Interface Between Two Media of Different Velocities, from Cross-Spread Shooting.* (In French).

B. Favre, Geophysical Prospecting, Vol. 3, No. 4, pp. 339-349, December 1955.

The problem is considered of how to determine, from dip-shooting data, the position in space of a reflecting horizon located underneath a refracting interface between two media of different velocities.

The author proposes a combination between a geometric solution and an analytical one, to obtain the quickest result.

(Author's Abstract).

56. *Instrumental Distortion and the Seismic Record.*

N. A. Anstey, Geophysical Prospecting, Vol. 4, No. 1, pp. 37-55, March, 1956.

This paper is presented to the geophysicist concerned wit the interpretation of seismic records. Those instrumental factors which can affect the validity of the records are detailed. Inferences are drawn relating to the picking, timing and grading of reflections, and the shooting of records in the field.

(Author's Abstract).

57. *On Seismic Wave Propagation in Anisotropic Media with Applications in the Betun Area, South Sumatra.*

A. H. Kleyn, Geophysical Prospecting, Vol. 4, No. 1. pp. 56-69, March, 1956.

An analytical solution of refraction problems in anisotropic media is based on the expression for the refraction angle in an uniaxial anisotropic medium with vertical axis and elliptic anisotropy. The theory is applied to a test on the anisotrpic behaviour of the sedimentay section in the vicinity of Betun, South Sumatra, employing the results from a refraction profile, a well velocity survey and a radial well survey. It is concluded that, in the Betun area, the anisotropy factor is variable with depth. Its maximum value may be as high as 1.15 in the middle part of the section.

(Author's Abstract).

58. *Traveltime Curves of Waves Reflected from Curvilinear Boundaries and their Interpretation.* (In Russian).

V. D. Zav'yalov & Y. V. Timoshin, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 118-129, 1955.

The question of the shape of the traveltime curve is discussed, and various forms of this curve are given for many special cases of the reflecting surface. In the general case, assumption of a hyperbolic shape of the traveltime curve is inadmissible. An analytic method of finding the traveltime curve is first given, and later a more convenient graphic procedure is given for its determination. The suggested method is based on the laws of geometric optics and naturally leads to only approximate solutions. The solutions found theoretically were later checked by experiments with an ultrasonic seismoscope designed by Riznichenko and others, and good agreement was found between the computed and experimental results.

59. *A Method for the Determination of Depth and Dip of a Reflecting Horizon from the Traveltime Curve of a Reflected Impulse.* (In German).

R. Zeuch, Gerlands Beitr. Geophys., Band 64, Heft 3, pp. 194-207, 1955.

The method described permits determination of the depth and dip of a reflecting horizon from the traveltime curve alone. The determination of the average velocity of the reflected impulse is included in the method. The effect of layers between the surface and the reflector is investigated qualitatively for a normal case by means of an example. The described method, taking advantages of certain simplifications, is based on the results of that investigation. An estimate of error indicates the accuracy of the values obtained in using the method. The application of the method is illustrated by a numerical example. The method is not applicable to the steep flanks of salt domes.

(Author's Abstract).

60. *On the Accuracy of Evaluation of Oscillograms.* (In German).
W. Härtel, Frequenz, Vol. 9, No. 8, pp. 264-273, August 1955.

A detailed examination of the factors which determine accuracy, such as thickness, sharpness and optical density of trace, slope, relative radius of curvature. Some examples are given.

(From Electrical Engineering Abstracts, B, December 1955).

61. *Application of Delay and Intercept Times in the Interpretation of Multi-Layer Refraction Time Distance Curves.*
S. M. Wyrobek, Geophysical Prospecting, Vol. 4, No. 2, pp. 112-130, June 1956.

The well known quantities, delay and intercept times, can be made fully uselful in the interpretation of multilayer refraction problems dealing with small undulating dips.

The identification of individual refractors is made by the use of reciprocal and intercept times and by applying an additional and useful relationship, namely that the delay time profile between two shot-points should match the half-intercept time profile when calculated using the true velocity of the refractor.

With a suitable arrangement of shot-points this relation permits us to obtain the true horizontal velocity of a refractor from one direction of shooting only.

Presentation of the refraction results in the form of time sections, similar to those used in reflection surveys, is often desirable. These sections can be converted easily into depth sections, once the overburden velocities are defined.

The use of the method is limited not only by the dip, but also by the depth of the refractor. Deep refractors can be, however, worked out by this method, by reducing a multilayer problem to that of two layers, using again the delay times.

(Author's Abstract).

62. *A Rapid Method of Determining the Form of a Seismic Refractor from Line Profile Results.*
L. H. Tarrant, Geophysical Prospecting, Vol. 4, No. 2, pp. 131-139, June 1956.

A set of refraction line arrival times can be readily converted into a set of delay-times providing the refractor velocity is known. If we then subtract the delay-time at the shot-point end, we arrive at a set of delay-times representing the refractor depths at the receiving end. This paper is concerned with the conversion of such a set of delay-times into a profile of the refractor.

The method is semi-graphical and very easy to apply. For each geophone station an arc of a circle is constructed, such that the envelope of the series of arcs represents the surface of the refractor. While the method is not quite exact, especially when the dips are large, it is of particular value in allowing for the effects of varying dips upon the offset distance. The method treats the overburden above the refractor as if it were of uniform velocity.

(Author's Abstract).

SEISMIC — THEORY & RESEARCH

63. *Reflection of an Acoustical Pressure Pulse from a Liquid-Solid Plane Boundary.*
T. W. Spenser, Geophysics, Vol. 21, No. 1, pp. 71-87, January 1956.

The problem treated is concerned with predicting the transient response of a system composed of a liquid layer, bounded above by a vacuum and below by a perfectly elastic solid, when excited by an arbitrary pressure applied uniformly over the surface of a spherical cavity located in the fluid. The Laplace transform of the displacement response is expressed in terms of an integral which is expanded in such a way that each term describes the contribution from one of the image sources. Each term may be evaluated exactly at points located on a vertical axis passing through the source. The final expression for the vertical displacement at axial points is composed of the acoustic afterflow, and correction terms. In solids for which Poisson's ratio is greater than one third the initial variation of the correction is toward positive values (corresponding to motion directed toward the interface). For Poisson's ratio less than one third the initial variation may be either positive or negative depending on the magnitude of the compressional velocity ratio. A surface wave is shown to exist regardless of the choice of parameters. The surface wave velocity is always less than it would be in the absence of the liquid.
(Author's Abstract).

64. *Small Three-Dimensional Seismic Models.*
L. Knopoff, Trans. Am. Geophys. Un., Vol. 36, No. 6, pp. 1029-1034, December 1955.

The fundamental theory of models is reviewed and application made to the case of three-dimensional laboratory models of seismic phenomena. The nature of usable transducers and media of transmission are considered from the standpoint of the bandwidth restrictions imposed by the modelling method. The experimental procedure is described and results for a model for Lamb's problem are obtained. The influence of imperfections of elasticity is also investigated; the results for a wax accord with theoretical predictions based upon a viscoelasticity of a simple type.
(Author's Abstract).

65. *Dispersion of Seismic Waves Near a Small Explosion.*
G. V. Keller, Trans. Am. Geophys. Un., Vol. 36, No. 6, pp. 1035-1043, December 1955.

The characteristics of the ground vibrations caused by the detonation of small dynamite charges were studied at distances from 10 to 3070 feet from the point of detonation. The motion which was observed could be separated into several types on the basic of velocity and particle motion paths. The major part of the recorded motion following the arrival of body waves exhibited strong dispersion. A comparison of this dispersion with that theoretically predicted for Rayleigh waves by Love, Sezawa and others, showed that these motions are probably Rayleigh waves of the first and second types. The complex particle motion orbits observed near the shot point are probably a result of the overlap of these two normal modes of surface wave propagation.

(Author's Abstract).

66. *Low Sound Velocities in High-Porosity Sediments.*
E. L. Hamilton, J. Acoust. Soc. Am., Vol. 28, No. 1, pp. 16-19, January 1956.

Recent study of shallow-water sediments off San Diego, California, revealed several stations at which the seismic velocity in the sediment was 2-3% lower than the velocity in the water just above the sediment. Comparison of the compressibility of the sediment with the ratio: sediment-velocity/water-velocity indicates that these high porosity sediments are approximately described acoustically by the velocity formula which applies to a suspension. References are given to theoretical explanations of the phenomena.

67. *On Surface Waves in Loose Materials of the Soil.*
A. Korschunow, Geophysical Prospecting, Vol. 3, No. 4, pp. 359-380, December 1955.

A three-component set of small mechanical leaf spring seismographs was used to observe the effects of hammering and small blasts in various soils. The theoretical concept of Rayleigh waves generated in a layer overlying a semi-infinite medium was confirmed. The disperion curves obtained corresponded well with theoretical curves.

It is concluded that all seismic pulses generate specific Rayleigh wave mechanisms in loose layers. Their penetration and frequency characteristics depend on the delivery of energy and the soil consistence.

It is shown that the investigation of near-surface layers of loose soils by the refraction method presents far more difficulties than has been assumed in the past.

Harmonic analysis of seismograms has been proved to be superior in the determination of the critical frequencies of generated surface waves.

Finally, a method of determining the absorption of surface waves is discussed.

68. *On the Effect of Poisson's Ratios of Rock Strata on the Reflection Coefficients of Plane Waves.*

O. Koefoed, Geophysical Prospecting, Vol. 3, No. 4, pp. 381-387, December 1955.

Calculations are presented of reflection coefficients of plane longitudinal waves incident at oblique angles on boundary waves between elastic media. It is shown that the manner in which these reflection coefficients vary with the angle of incidence is strongly affected by the values of the Poisson's ratios of the two media. It appears that, contrary to a conclusion arrived at by Muskat and Meres, the reflection coefficient may vary appreciably with the angle of incidence in the range between 0° and 30°. Possibilities of practical application of this phenomenon are discussed.

(Author's Abstract).

69. *Application of High Frequency Seismic Techniques.*

K. E. Burg, Geophysics, Vol. 20, No. 2, p. 376, April 1955. (Abstract only of paper read at the Annual Meeting of the S.E.G., New York, March 1955).

Conventional seismic techniques in the past have used frequencies primarily within the band of 20-70c/sec. The new H.R. (high resolution) system recently developed for the recording of higher frequency reflections has opened a new field in seismic exploration. The specifications of a recording system designed to record these higher frequency reflections are somewhat different from those suitable for conventional recording. As would be expected, many new problems have been encountered and considerable new knowledge has been added.

The H.R. system is applicable in shallow-reflection areas, in areas where higher resolution permits the detection of significant changes in thickness and lithology of the formations, and in areas where the thickness and travel time through low velocity near-surface formations must be determined. The H.R. system is also applicable to various mining overburden and ground water problems.

A number of examples show these various applications.

70. *The Propagation of Elastic Waves in Anisotropic Media.* (In German).

K. Helbig, Geophysical Prospecting, Vol. 4, No. 1, pp. 70-81, March, 1956.

In seismic underground surveys carried out by Seismos GmbH in siderite mines of Siegerland (Germany) anomalies in velocities have been found which could be explained only by the assumption of slates being aeolotropic. In this paper some of the peculiarities connected with the propagation of elastic waves in aelotropic media—especially those consisting of thin beds of isotropic material—are discussed. Schlieren pictures of wave-fronts are presented, which show the validity of the theory.

(Author's Abstract).

71. *Features of Seismic pP and PP Rays.*
K. E. Bullen, Mon. Not. Roy. Astronom. Soc., Geophys. Suppl., Vol. 7, No. 2, pp. 49-59, October 1955.

Previous theoretical work on features of seismic rays has been extended to the case of pP and PP rays. It is shown that, for a wide class of velocity variations in the Earth's outer mantle, there is a cusp in the pP travel time curve which corresponds to a ray which leaves a focus at finite depth in a direction inclined at a finite angle above the horizontal through the focus. It is also shown that the cusp is in general theoretically similar to the cusp in the PKP case. A method is given for locating this cusp for particular focal depths and is illustrated in an application to the Jeffreys-Bullen travel time data. The general influencee of the 20° discontinuity is discussed. Comment is made on conventions in naming pP and PP rays.

(Author's Abstract).

72. *The Attenuation of Compression Waves in Lossy Media.*
L. Knopoff, Bull. Seismol. Soc. Am., Vol. 46, No. 1, pp. 47-56, Jan., 1956.

By means of modelling experiments on a wax slab, oil-coupled lithium sulphate transducers are found to have excellent directional properties as seismic modelling transducers. Investigation of the several orders of multiple reflection amplitudes shows that consistency in the measured reflection coefficients for the spherical wave fronts is easily achieved if a loss mechanism of the internal viscosity type is attributed to the wax.

(Author's Abstract).

73. *Rayleigh Wave Dispersion in the Period Range* 10 *to* 500 *Seconds.*
M. Ewing & F. Press, Trans. Am. Geophys. Un., Vol. 37, No. 2, pp. 213-215, April 1956.

A composite Rayleigh wave dispersion curve obtained from earthquake seismograms is presented for the period range 10-500 sec. For periods greater than 75 sec. the dispersion is primarily influenced by the shear velocities gradient in the mantle. For periods less than 75 sec. the effect of the crustal layer is most important. Brief discussions of the spectrum of the initial impulse and stationary values of group velocity, as they influence the character of seismograms, are given.

74. *On the Resonant Properties of Interference Waves in an Elastic Layer.* (In Russian).
I. J. Keilis-Borok, Akad. Nauk SSSR, Trudy Geofiz. Inst., 22 (149) pp. 50-58, 1954.

The resonant properties of sine-form interference waves of the Naimark type, that were set up in the centre of expansion (concentrated in the elastic layer between two half spaces) are tested.

75. *The Multiple Reflections of Waves in an Elastic Layer.* (In Russian).
N. W. Swolinsky, Akad. Nauk SSSR, Trudy Geofiz. Inst., 22 (149) pp. 26-49, 1954.

This paper treats the problem of multiple reflections of waves in an elastic layer that lies in an elastic half space. It is first explained how the local reflection-coefficient is characterised by the strength of the reflected waves in the front zone. In some types of problem the reflection coefficient is calculated from headwaves; results are shown graphically. The calculations carried out are mainly for triple reflections. The results acquired to date are also very useful for the solution of symmetrical-axis problems.

76. *Observations on the Importance of the Ground Conditions for Seismic and Dip Measure-*ments. (in Russian).
N. F. Sawarenski, Akad. Nauk SSSR, Trudy Geofiz. Inst., 22 (149), pp. 102-110, 1954.

The influence of local disturbances and dips on the work of the seismic and dip measuring stations is studied for various ground conditions.

77. *The Nature of Elastic Waves Produced in Actual Media by a Harmonic Source.* (In Russian).
Y. V. Karus & I. P. Pasechnik, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 89-100, 1955.

The nature and properties of elastic vibrations in rocks produced by a harmonic source have been experimentally determined. Travel-time curves and the curves of amplitude variation were studied. These experiments have shown that the observed waves are complex, being the result of different interfering longitudinal, transverse and surface waves. Longitudinal waves predominate at distances greater than 8-10 wavelengths; transverse and surface waves were found to be more intense, with Rayleigh waves predominant. Coefficients of energy absorption in the medium were determined by averaging successive amplitudes and could be reliably found for dominant waves.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

78. *Surface Waves in Energy Absorbing Media.* (In German).
E. Hardtwig, Ann. Geofis., Vol. 7, No. 2, pp. 143-193, 1954.

The limits of Hooke's law with relation to the propagation of surface waves in media not perfectly elastic are indicated at first, then the theories of Maxwell, Larnor-Jeffreys and Galitzin for energy absorbing media are discussed.

A second part gives full treatment to Galitzin's theory for a medium with internal friction. It is assumed that the damping of waves does not depend on the frequency or the phase velocity.

The third part is concerned with the setting up of a solution for a firmo elastic medium.

79. *Study on Surface Waves, VIII. Nomogram for the Phase Velocity of Love Waves and Maximum Thickness of the Surface Layer.*
Y. Sato, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 31, Pt. 2, pp. 81-88, 1953.

A monogram has been devised to obtain the velocity of Love waves corresponding to any given state of media, or to get a material constant by means of the velocity and period data. If the velocity of 'S' waves and the rigidity of both media are given, and the period and phase velocity of Love waves are observed, the thickness of the surface layer can be determined from the nomogram; a maximum thickness can be determined if the velocity of 'S' in the upper medium, phase velocity, and period are given.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

80. *Study on Surface Waves, IX. Nomogram for the Group Velocity of Love Waves.*
Y. Sato, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 31, pt. 4, pp. 255-260, 1953.

81. *Study on Surface Waves, X. Equivalence of 'SH' Waves and Sound Waves in a Liquid.*
Y. Sato, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 32, Pt. 1, pp. 7-16, 1954.

It is shown that 'SH' waves and sound waves in a liquid are equivalent if the frequency, wavelength, and velocity of body waves are equal in the two problems and if the density is inversely proportional to the rigidity. The free surface of one corresponds to a fixed surface of the other and displacement in one to stress in the other.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

82. *Boundary Velocities in Some Metamorphic and Chrystalline Rocks.* (In Russian).
I. S. Berzon, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 101-117, 1955.

Boundary velocities of seismic waves were determined experimentally in several vertically stratified matamorphic rocks bordering on crystalline formations by the method of correlation of refracted waves. The identification of different strata often cannot be reliably made on the basis of determined velocity. Comparison of the characteristic variations in the amplitudes of the waves is recommended.

83. *Propagation of Rayleigh Waves in a Layer Resting on a Yielding Medium.*
S. C. Das Gupta, Bull. Seismol. Soc. Am., Vol. 45, No. 2, pp. 115-119, 1955.

The effect of an underlying elastic medium on the propagation of Rayleigh waves in a homogenous layer is considered, and the results are compared with those of Sezawa and Kanai for the propagation of waves in a layer lying on a rigid foundation. Assuming that a Rayleigh-type wave is propagated in the medium in question, an approximate value of the constant of proportionality between the upward thrust on the lower surface of the layer and the vertical displacement is determined (assuming a linear relationship). If Rayleigh waves of 20-sec. period travel with velocity of 0.03 kmps., and the velocity of shear waves is 3.34 kmps, the constant is 1.5×10^5 dynes/cm.^{3}. From boundary conditions and from this approximate value the existence of a minimum group velocity is shown.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

84. *Experimental Results on Refracted Waves in Media with Small Differences in Velocities.* (In Russian).
A. M. Yepinat'yewa, Akad Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 130-136, 1955.

Experiments showed that refracted waves can be formed with only small differences in velocities of adjacent strata. Refractions were observed for velocity ratios of 0.90 or even 0.98 in the velocity range 5.0 to 5.5 kmps. Thus it is shown that changes in formation cannot be shown by travel time curves, but by dynamic characteristics such as a decrease in amplitude of seismic waves.

85. *Experimental Studies on the Mechanism of Generation of Elastic Waves. I.*
K. Kasahara, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 30, Pt. 3, pp. 259-168, 1952.

To investigate the mechanism of generation of elastic waves, model experiments were made using agar-agar as the elastic medium and a wave transmitter constructed from parts of a dynamic loudspeaker. The first experiment was determination of the behaviour of the surface of a homogeneous semi-infinite elastic body under the effect of an impulsive external force acting in a vertical direction at a point on the surface.

86. *Experimental Studies on the Mechanism of Generation of Elastic Waves. II.*
K. Kasahara, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 31, Pt. 1, pp. 71-79, 1953.

A theoretical study of wave phenomena on the surface of a semi-infinite elastic body subjected to an external impulsive force.

87. *Experimental Studies on the Mechanism of Generation of Elastic Waves. III.*
K. Kasahara, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 31, Pt. 3, pp. 235-243, 1953.

It is shown how a free surface wave is produced from the initial deformation of the surface.

88. *An Amplitude Study on a Seismic Model.*
C. S. Clay & H. McNeil, Geophysics, Vol. 20, No. 4, pp. 766-773, October 1955.

The measured amplitudes of two seismic events which have travelled through a two-layer seismic model are compared with the amplitudes calculated from plane wave reflection and transmission theory.

The relative amplitudes of the events, one a dilatational-dilatational and the other a dilatational-to-shear conversion event, are found to be in agreement with calculations based on reflection theory for plane waves, after correction for $1/r^2$ divergence.

(Author's Abstract).

89. *A Coal Seam as a Guide for Seismic Energy.*
F. F. Evison, Nature, Vol. 176, No. 4495, pp. 1224-5, December 24, 1955.

In a letter to 'Nature' a description is given of a dispersive train of vibrations, resembling an internal Love wave, that has been observed during seismic experiments in the Mangapehi State Coal Mine, New Zealand. It is suggested that coal mines may offer particularly favourable conditions for the study of this type of wave, and also that guided waves may find useful applications in mining.

90. *Diffraction of Sound at a Thin Bounded Plate in a Liquid.*
L. M. Lyamshev, Akust. Zh. ,Vol. 1, No. 2, pp. 121-125, April-June, 1955.

A calculation is made of the scattering of sound by a thin plate fixed in an infinite rigid screen immersed in a liquid, taking account of the vibrations set up in the plate.

(From Wireless Engineer (Abstracts), February 1956).

91. *Wave Propagation in a Stratified Medium.*
G. W. Postma, Geophysics, Vol. 20, No. 4, pp. 780-806, October 1955.

A periodic structure consisting of alternating plane, parallel, isotropic and homogeneous elastic layers can be replaced by a homogeneous, transversely isotropic material as far as its gross-scale elastic behaviour is concerned. The five elastic moduli of the equivalent transversely isotropic medium are accordingly expressed in terms of the elastic properties and the ratio of the thicknesses of the individual isotropic layers. Imposing the condition that the Lamé constants in the isotropic layers are positive, a number of inequalities are derived limitations of the values the five elastic constants of the anisotropic medium can assume. The wave equation is derived from the stress-strain relations and the equation of motion. It is shown that there are in general three characteristic velocities, all functions of the direction of the propagation. A graphical procedure is given for the derivation of these characteristic velocities from the five elastic moduli and the average density of the medium. A few numerical examples are presented in which the graphical procedure is applied. Examples are given of cases which are likely to be encountered in nature, as well as of cases which emphasize the peculiarities which may occur for a physically possible, but less likely, choice of properties of the constituent isotropic layers. The concept of a wave surface is briefly discussed. It is indicated that one branch of a wave surface may have cusps. Finally, a few remarks are made on the possible application of this theory to actual field problems.

(Author's Abstract).

92. *Mechanical Impedance Measurements of Soils.*
W. R. Runyan & R. E. Anderson, J. Acoust. Soc. Am., Vol. 28, No. 1, pp. 73-76, January 1956.

A method of measuring the mechanical impedance of the earth is described, and some experimentally measured impedances as functions of water content, soil character and source diameter are given. A comparison of the measured impedance with some previous theoretical work is also included.

(Author's Abstract).

93. *Underwater Sound Reflection from a Corrugated Surface.*
E. O. LaCasce & P. Tamarkin, J. Applied Physics, Vol. 27, No. 2, pp. 138-148, February 1956.

Theories of rough surface reflection by Rayleigh, Eckart and Brekhovskikh are utilized to calculate the dependence, on surface and radiation parameters, of the amplitudes of reflected radiation when an acoustic beam is incident on a pressure-release surface with sinusoidal corrugations. The results of these theories are compared, with emphasis on the assumptions used. Experimental results for the reflection of an under-water acoustic beam from this type of surface are presented and compared with each of the theories. The best agreement between theory and experiment is obtained for surfaces of small slope, indicating that this criterion is basic to the validity of the theories. However, surprisingly similar results are obtained for surfaces of large slope. The theories seem to predict the behaviour of the lower orders of reflection more closely than that of the higher ones. Good agreement between theory and experiment is obtained for directions of reflection and for cut-off frequencies.

(Author's Abstact).

94. *On the Propagation of Steady Oscillations in a Layer Between Two Semi-Spaces.* (In Russian).
V. I. Keylis-Borok, Akad. Nauk SSSR Geofiz. Inst. Trudy, No. 20 (147). pp. 20-35, 1953.

Steady sinusoidal oscillations in a perfectly elastic plane-parallel layer in contact with two semispaces are investigated. The media are assumed to be homogeneous, isotropic and perfectly elastic. Oscillations are obtained by applying a concentrated force varying sinusoidally with time at right angles to the layer.

Formulae are derived for the oscillatory displacements at points within the layer and the surrounding media. The natural frequencies of the displacements are also determined. The natural frequencies near the point of application of the force have sharp resonances. With increasing distance from the applied force, the amplitudes of the oscillations rapidly attenuate. The derived formulae can probably be used for determining the thickness of the layer, if the velocity of wave propagation is known.

(From Geophysical Abstracts 160, U.S. Geol. Survey).

95. *On the Resonant Properties of Interference Waves in a Layer.* (In Russian).
V. I. Keylis-Borok, Akad. Nauk SSSR Geofiz. Inst. Trudy, No. 22, (149), pp. 50-59, 1954.

This is a continuation of the study of the propagation of steady waves in a plane-parallel layer between two semispaces. The media are assumed to be homogeneous, isotropic and perfectly elastic; the waves are produced by a concentrated force within the layer varying sinusoidally with time. The interference waves become dominant as soon as the distance from the force becomes large compared with the thickness of the layer. The case of a force acting on the boundary plane of the layer is also studied. Results are presented in formulae and graphs. The results correspond to observations in seismic prospecting.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

96. *Model Seismology* (*Part* 1).
Y. Kato & A. Takagi, Tohoku Univ. Sci. Repts., 5th ser., Vol. 7, No. 1, pp. 35-44, 1955.

Propagation of elastic waves produced in a thin plate by an ultrasonic pulse and in a medium of two homogeneous plates divided by a step-shaped boundary was studied experimentally. Both horizontal and vertical motions were measured. In the first, two predominant phases were found in every seismogram, the first consisting of large motion with a horizontal component and small vertical component (3:1 to 4:1) which are identified as primary body waves. The second phase exhibits the character of Rayleigh waves. In the complex structure, the waves are not so simple, but the traveltimes are well explained by x-ray theory.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

97. *The Use of Ultrasonic Waves in the Investigation of the Structure of Homogeneous Geologic Formations.* (In Polish with French & Russian Summaries).
I. Malecki & W. Koltonski, Archiwun Gornictwa i Hutnictwa, Vol. 3, No. 2, pp. 157-204, 1955.

The laws of propagation of ultrasonic waves in different media are discussed, and experiments are described which were made in the laboratory and in the field for the determination of the velocity of the elastic waves in various media, their damping properties at different frequencies, and the reflecting properties at the boundaries of different layers. The results of the measurements on anhydrite, rock salt, limestone, coal and sandstone are presented on graphs and in tables.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

98. *The Seismic Buried Pulse.*
C. L. Pekeris, Nat. Acad. Sci. Proc., Vol. 41, No. 9, pp. 629-639, 1955.

An exact solution is given for the motion of the surface of a uniform elastic half-space produced by a point pressure pulse situated at a depth 'H' below the surface and varying with time like the Heaviside unit function H(t). This source excites both P and SV waves. When the epicentral distance is greater than $H/\sqrt{2}$ for a medium in which the elastic constants λ and μ are assumed equal, the P wave is followed by a diffracted P wave, derived from the SV wave, which arrives before the direct SV wave.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

99. *Study on Surface Waves XI. Definition and Classification of Surface Waves.*
Y. Sato, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 32, Pt. 2, pp. 161-168, 1954.

Surface waves are defined as waves propagated in a medium with a single or several parallel plane boundaries with the wave front perpendicular to the boundary surface(s). The amplitude distribution may be classified in two groups, one expressed by an exponential function (as in Rayleigh waves) and the other sinusoilal. A classification of possible surface waves is prepared from the permutations and combinations of these types in media with both free surfaces and rigid boundaries.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

100. *On Love Waves in Heterogeneous Media.*
Z. Suzuki, Tokyo Univ. Sci. Repts., 5th ser., Vol. 7, No. 2, pp. 82-93, 1955.

Effects of the state of heterogeneous media at infinite depth on the propagation of Love waves are studied.

101. *The Changing of the Flux of Seismic Energy with Epicentral Distance.* (In Russian).
S. L. Solov'yev & E. A. Dzhibladze, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 5, pp. 462-463, 1955.

In an infinite homogeneous space the energy E of the elastic waves decreases inversely with the square of the distance r from the source of the disturbance ($E = 1/r^2$). In a semispace in the vicinity of the boundary, the energy decreases more rapidly because a certain amount of the energy in the incoming spherical waves is transformed into surface waves that propagate along the boundary. The energy of transverse waves produced by numerous earthquakes in the Caucasus with the focal depths ranging from 5 to 20 km. has been found to be related to distance by the formula $E = a/r^{3.8} \pm 0.3$. This is close to Lamb's formula of $E = a/r^4$.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

102. *A Comparison of Additive and Multiplicative Compounding.*

K. Dyk, Geophysics, Vol. 21, No. 2, pp. 361-367, April 1956.

Additive and multiplicative compounding of seismometer outputs are compared. In the equations developed for multiplicative compounding some terms involve products of signal and noise, and an arbitrary division of these terms between signal and noise is made to facilitate handling. Under the assumptions made it is developed that for low signal-to-noise ratios (less than 0.8) additive compounding provides a greater improvement in signal-to-noise ratio than does multiplicative compounding unless large numbers of units are compounded.

(Author's Abstract)

103. *Theory of Propagation of Elastic Waves in a Fluid-Saturated Porous Solid. Part I. Low-Frequency Range.*

M. A. Biot, J. Acoust. Soc. Am., Vol. 28, No. 2, pp. 168-178, March 1956.

A theory is developed for the propagation of stress waves in a porous elastic solid containing a compressible viscous fluid. The emphasis is on materials where fluid and solid are of comparable densities as for instance in the case of water-saturated rock. This paper is restricted to the lower frequency range where the assumption of Poiseuille flow is valid. It is found that the material may be described by four non-dimensional parameters and a characteristic frequency. There are two dilatational waves and one rotational wave. The physical interpretation of the result is clarified by treating first the case where the fluid is frictionless. The case of a material containing a viscous fluid is then developed and discussed numerically. Phase velocity dispersion curves and attenuation coefficients for the three types of waves are plotted as a function of the frequency for various combinations of the characteristic parameters.

(Author's Abstract).

104. *Theory of Propagation of Elastic Waves in a Fluid-Saturated Porous Solid. Part II. Higher Frequency Range.*

M. A. Biot, J. Acoust. Soc. Am., Vol. 28, No. 2, pp. 179-191, March 1956.

The theory of propagation of stress waves in a porous elastic solid developed in Part I for the low-frequency range is extended to higher frequencies. The breakdown of Poiseuille flow beyond the critical frequency is discussed for pores of flat and circular shapes. As in Part I the emphasis of the treatment is on cases where fluid and solids are of comparable densities. Dispersion curves for phase and group velocities along with attenuation factors are plotted versus frequency for the rotational and the two dilatational waves and for six numerical combinations of the characteristic parameters of the porous systems. Asymptotic behaviour at high frequency is also discussed.

(Author's Abstract).

105. *Disturbances of Cylindrical Origin in an Isotropic Medium.*

S. K. Chakraborty, Geofis. Pura e Appl., Vol. 33, No. 1, pp. 9-16, Jan.-April 1956.

The disturbances in an infinite homogeneous isotropic and perfectly elastic medium produced by a source operating on a small portion of the inner surface of a cylindrical hole are investigated.

106. *Seismic Wave Studies Over a High-Speed Surface Layer.*
F. Press & M. B. Dobrin, Geophysics, Vol. 21, No. 2, pp. 285-298, April 1956.
The propagation of compressional, shear and surface waves was studied along a 3,200 ft. profile at a location where a 95 ft.-thick surface layer of Austin chalk, with a compressional velocity of about 9,900 ft./sec., overlies a 400 ft. section of Eagle Ford shale with a speed of about 6,500 ft./sec. Woodbine sand, with a velocity of about 9,900 ft./sec., underlies the shale.

107. *Theories of a Resonance Method to Measure the Acoustic Properties of Sediments.*
W. J. Toulis, Geophysics, Vol. 21, No. 2, pp. 299-304, April 1956.
The theory of resonance for a pressure release cylindrical chamber is explored and equations are derived for determining absolute values of the velocity of sound and the attenuation constant in sediment samples.

108. *A Resonant Chamber Method for Sound Velocity and Attenuation Measurements in Sediments.*
G. Shumway, Geophysics, Vol. 21, No. 2, pp. 305-319, April 1956.
Sound velocity and attenuation measurements in unconsolidated marine sediments have been made by a resonance method which utilizes a thin-walled plastic cylinder as a pressure-release container to hold samples. Relatively undisturbed sediment samples were obtained by diver, in shallow water. Deep sea samples were obtained from drill cores.

109. *A Marine Seismic Model.*
G. P. Sarrafian, Geophysics, Vol. 21, No. 2, pp. 320-336, April 1956.
A model for the study of marine seismic phenomena is described. Study of multiple-reflection phenomena forms the basis for the course of experiments. It is shown that the multiple-reflection phenomenon of a disturbance with slowly decaying amplitude may be duplicated in the model. Multiple-reflection problems are studied in which the bottom of the water layer is tilted or thin. A mass of air bubbles is shown to be use of in attenuating multiple reflections. The possible application of the marine model in a search for information about certain problems in field prospecting is suggested.

(Author's Abstract).

110. *Scattering of Sound by Sound.*
U. Ingard & D. C. Pridmore-Brown, J. Acoust. Soc. Am., Vol. 28, No. 3, pp. 367-369, May 1956.
Calculations and measurements are reported of the summation and difference frequency components which are scattered from the interpretation region of two sound beams in air intersecting each other at right angles.

GRAVITY — GENERAL

111. *Relative Determination of the Density of Surface Rocks and the Mean Density of the Earth from Vertical Gravity Measurements.*
W. Domzalski, Geophysical Prospecting, Vol. 3, No. 3, pp. 212-227, Sept., 1955.
The gravity difference between two stations, one at the surface and the other underground vertically below the former and at a given distance from it, depends on the mean density of the earth, σ_m, as well as on the density of the layer of rock contained between the two stations. When one of these densities is known, the other can be computed from the gravity difference. The reliability of this determination

depends on the relative accuracies with which σ_m and σ can be obtained. These accuracies are discussed.

To investigate the problem, three sets of gravity measurements were made under differing conditions.

The results demonstrated that the accuracy varied with the conditions prevailing in the area where the observations were made. It is concluded that the gravity difference between a surface and an underground station can be used satisfactorily to determine the average density of a rock layer in situ and en bloc, using the standard value for the mean earth density.

112. *Regional Gravity Survey in Northeastern Oklahoma and Southeastern Kansas.*
K. L. Cook, Geophysics, Vol. 21, No. 1, pp. 88-106, January 1956.

A regional gravity survey in northeastern Oklahoma and southeastern Kansas was carried out in connection with studies of the deflection of the vertical. The resulting Bouguer anomaly map is shown. Lack of correlation, and in some cases agreement, of gravity with known geology is discussed.

113. *Regional Gravity Survey in Salk Lake and Utah. Counties, Utah.*
K. L. Cook & J. W. Berg, Jr., A paper read at the Annual Meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published).

Gravity measurements were made at 1,100 stations over an area of about 2,100 square miles, and the results have been compiled in a Bouguer gravity anomaly map.

114. *The Results of Gravimeter Observations Between the Stations of the Primary Gravity Base-Line of Great Britain.*
I. L. Watson, Mon. Not. Roy. Astronom. Soc., Geophys. Suppl., Vol. 7, No. 2, pp. 60-70, October 1955.

115. *On the Values of Gravity at St. Anne (Alderney), St. Peter Port (Guernsey) and St. Helier (Jersey).*
A. A. Day, Mon. Not. Roy. Astronom. Soc., Geophys. Suppl., Vol. 7, No. 2, pp. 76-79, October 1955.

116. *The Establishment of an International Gravity Standard.*
G. P. Woolard, J. C. Rose & W. E. Bonino, Trans. Am. Geophys. Un. ,Vol. 37, No. 2, pp. 143-155, April 1956.

A programme of pendulum and gravimeter measurements for the establishment of a gravity standard between Mexico and Alaska is described. The problems involved in obtaining precise measurements with pendulums are discussed, values for three independent sets of pendulum measurements and gravimeter measurements are compared.

117. *Densities and Porosities of Rocks.*
E. J. Polak, Mine & Quarry Engnrg., June 1955.

Numerous rock samples from Cannock Chase, Staffs., England, were examined to ascertain the following properties: grain density, dry density, saturation density and porosity. The resulting saturation-density/porosity curves are useful in finding values of rock density for correction data in gravity surveys.

118. *The Deflection of the Vertical in the Western and Central Mediterranean Area.*
I. Fischer, Bull. Geod., No. 34, pp. 343-353, 1954.

119. *A Study on the Deviation of the Plumb-Line in Japan.*
Y. Kawabata, Geophys. Mag., Vol. 26, No. 3, pp. 139-213, 1955.

120. *Gravity Maps of Central Europe from Gravimeter Measurements.* (In German).
A. Schleusener & H. Closs, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 9, pp. 85-108, 1954.

121. *Gravity Measurements over the Cumberland Basin, Nova Scotia.*
G. D. Garland, Canadian Min. Metal. Bull., Vol. 48, No. 515, pp. 140-148, 1955.

122. *Correlation of Gravity and Magnetic Observations with the Geology of Blanco and Gillespie Counties, Texas.*
V. E. Barnes, F. E. Romberg, & W. A. Anderson, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 9. Fasc. 9, pp. 151-162, 1954.

123. *Preliminary Notes on the Gravimetry of Sardina: Gravimetric Profile Across the Plane of Campidano.* (In Italian).
R. Trudu, Ser. Geol. Italia Boll., Vol. 75, (1953), Fasc. 2, pp. 928-940, 1954.

124. *Presentation of a Gravity Map of French Morocco.* (In French).
J. Marcais, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 9, Fasc. 9, pp. 113-114, 1954.

125. *Gravity Investigations in the Hockley Salt Dome, Harris County, Texas.*
W. E. Allen, H. J. Caillouet, & L. Stanley, Geophysics, Vol. 20, No. 4, pp. 829-840, October 1955.

126. *Gravity Measurements in North America with the Cambridge Pendulum Apparatus. II.*
G. D. Garland, Proc. Roy. Soc., A, Vol. 233, No. 1193, pp. 203-213, December 20, 1955.

The methods described in the first paper of this series have been used to establish ten further pendulum stations, extending from Lethbridge, Alberta, to Fairbanks, Alaska. A range of over 4300 mgals. is thus covered by the observations made in North America with the Cambridge pendulums. As was done previously, the value 980.6220 cm./s^2 has been tentatively adopted for Ottawa. On this basis, the value obtained for Fairbanks, the most northerly station, is 982.2477 cm./s^2.

GRAVITY — INSTRUMENTAL

127. *Modern Methods of Gravity and Magnetic Interpretation.*
S. Hammer, Proceedings of the 4th World Petroleum Congress, Section I, pp. 635.

Modern interpretation techniques in use under development are reviewed and illustrated by selected maps and figures. These include "residual" and "second derivative" maps, "resolution", "continuation", "statistics" and "electronic computations". Underground observations to yield a third dimension in exploration are included.

128. *Tidal Gravity Corrections for* 1955.
J. Goguel, Geophysical Prospecting, Vol. 3, Supplement No. 2, June 1955.

Corrections for tidal gravity are provided in tabular form for the meridians 135° E Greenwich and 105° W Greenwich respectively, to cover the last six months of 1955. It is explained how the tables may be used for wide areas either side of the above meridians by applying the local time at the observation point.

129. *Today's Methods of Gravity Interpretation.*
S. Hammer, Oil & Gas J., Vol. 54, No. 11, pp. 144-145, July 18, 1955.

Recent developments in gravity interpretation techniques reveal a definite trend toward more quantitative evaluation and use of the data. Examples are given to illustrate the advantages of the 'second derivative' method of interpretation over the 'residual' method. It is stressed that the latter, being more sensitive to data errors, demands high quality data to work on.

Other advances briefly described are: the continuation technique of interpretation, the use of electronics to speed calculations, and the prospects of a borehole gravimeter

130. *Tidal Gravity Corrections for* 1956.
Service Hydrographique de la Marine, & Compagnie Generale de Geophysique, Geophysical Prospecting, Supplement No. 4, Vol. 3, 77p., December 1955.

A set of tables giving hourly values of corrections for tidal gravity, including the factor of 1.2 for the elasticity of the earth. The tables have been calculated for the meridians 15° E Greenwich, 135° E Greenwich and 105 °W Greenwich respectively, and for the times corresponding to these meridians. Interpolations can be made to determine values for wide areas either side.

131. *A Method for Absolute Measurement of Gravity: the Roto-Gravimeter.* (In Italian).
E. Medi, Ann. Geofis., Vol. 7, No. 4, pp. 487-790, 1954.

A method is discussed for an absolute measurement of the constant of gravity. This method is based on the form taken by a liquid set in rotation around an axis parallel to the direction of the acceleration of gravity at the place of observation. By measuring the focal distance of the paraboloid of revolution thus obtained, and the period of rotation of the system, it is possible to obtain a value of 'g'. There are no temperature effects with this method of measurement, and further sources of error, normally present in other methods, are eliminated.

(Author's Abstract).

132. *The Study of the North American AG*1 *Gravimeter No.* 125 *of the Instituto di Geofisica Mineraria of the Universita di Cagliari.* (In Italian).
R. Trudi, Ser. Geol. Italia Boll., Vol. 75, (1953), Fasc. 2, pp. 940-966, 1954.

A detailed description is given of the North American AG1 gravimeter followed by an analysis of its functioning, and its behaviour under different conditions of operations, based on Trudu's experiments and observations and on published material.

(From Geophys. Abstracts 161, U.S. Geol. Survey).

GRAVITY INTERPRETATION

133. *Gravity Variations in Surveys Across Geological Boundaries.*
G. C. Colley, Geophysical Prospecting, Vol. 3, No. 4, pp. 403-424, December 1955.

The paper discusses the variations of Elevation Correction Factor (E.C.F.) across various stratigraphical and structural occurrences with particular reference to the dipping bed, fault and horst. Graphs are prepared giving E.C.F. variations for various angles of dip and a method is suggested for application in the field. Errors in the linear variation that is commonly used for small angles of dip are discussed.

The second part of the paper consist of the application to interpretation of (1) Change of gravity dip and (2) The gravity inversion. It is shown how from a gravity map the dip, position of outcrop and thickness of a dipping bed can be determined. The last part shows how anticlines can give rise to negative anomalies and that in the direction of dip similar structures can at one point have no surface expression and afterwards invert to positive anomalies. The danger of attempting to predict the size of structures in such areas is emphasised.

(Author's Abstract).

134. *Numerical Determination of Gravitational Anomalies for a Linear Variation of Density of Formations with Depth.* (In Russian).

A. N. Timifeev, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 181-184, 1955.

In interpreting the results of gravimetric surveys the excess of density of the disturbing body over that of surrounding formations is assumed. The density of the latter is often chosen on the basis of specimens from upper layers, whereas usually density rapidly increases with depth and this increase should be taken into account. The effect of a linear variation of density has been computed for disturbing bodies of the shape of a horizontal infinite prism, a vertical discontinuity, and a horizontal layer of infinite dimensions. The results of the computations are given in tables and graphs.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

135. *Interpretation of the Results of Magnetic and Gravimetric Surveys with the Aid of Modern Electronic Computing Equipment.*

Dr. E. G. Kogbetliantz, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March, 1956. (Not yet published).

The fantastic speed with which modern electronic computers perform fundamental arithmetic operations opens unlimited possibilities for improving the scope and accuracy of technological computations. This paper discusses the use of electronic data-processing machines for the computation of the regional anomaly, derivative maps, and the continuation to various depths from a given observed anomaly map.

GRAVITY — THEORY & RESEARCH

136. *Schweydar's Formula for the Regional Effect of 'g'.* (In German).

K. Jung, Zeitschr. für Geophys., Vol. 20, No. 1, pp. 47-64, 1954.

The general theory is in agreement with Schweydar, whose formula for the calculation of the regional effect of gravity is derived. Its range of application is discussed.

137. *Gravity Measurements in a Vertical Shaft.*

W. Domzalski, Inst. Min. & Metal. London Bull., No. 571, pp. 429-445, 1954.

A Worden Gravimeter was used to take measurements in a vertical shaft at Snowdon Colliery, Kent. The effect of the shaft is calculated.

Fourteen stations were occupied at various depths to 2,945.5 feet. Densities were determined from the distance and gravity intervals between stations.

138. *The Geologic Causes of Gravity Anomalies.*

R. J. Watson, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March 1956. (Not yet published).

The appearance on gravity maps of various kinds of anomalies to be expected in a basin area is demonstrated by means of synthetic examples. Conditions of density contrast and structural relief necessary to produce detectable anomalies are shown. The possibilities of these favourable conditions being present in the Mid-Continent area of the U.S.A. are briefly considered.

MAGNETIC — GENERAL

139. *Magnetic Prospecting for Iron Ores in Jamaica.*

S. A. Vincenz, Geophysics, Vol. 20, No. 3, pp. 593-614, July 1955.

Two ground magnetometer surveys over iron ore deposits in Jamaica are described and the results of the observations interpreted. A conclusion is reached that, in the case of small-scale near-surface deposits whose approximate position is already known, ground magnetometer surveys can be superior to those made from the air because of their smaller cost and greater power of resolution in rough terrain.

140. *A Theoretical Map of the Basement in Indiana from Aeromagnetic Data.*
I. Zietz & J. R. Henderson, A paper read at the Annual Meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published).

An aeromagnetic map of Indiana, U.S.A., has been compiled on a scale of 1:500,000 from published USGS aeromagnetic county maps. A map of the pre-Cambrian basement rocks has been constructed from depth determinations of more than 80 isolated aeromagnetic anomalies. The magnetic trends on the basement rocks are in general similar to the trends of the structure contour map of the top of the Trenton (Ordovician) limestone. There is also excellent agreement between the map and the six depths to basement rocks found by well drilling.

The contours on the basement rocks indicate the possible existence of a major northwest-striking ridge approximately 50 miles wide that does not appear on the structure contour map on the top of the Trenton limestone. The existence of the ridge is partly confirmed by large gravity and magnetic anomalies at almost the same place.

141. *Regional Geophysical Studies in the Uravan District, Colorado.*
H. R. Joesting & P. E. Byerly, A paper read at the Annual Meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published).

Regional gravity and aeromagnetic surveys have been conducted in the Uravan district of southwest Colorado.

142. *Tunis to Lisbon Airborne Magnetometer Profile.*
W. B. Agocs & K. Isaacs, Geophysical Prospecting, Vol. 4, No. 1, pp. 10-23, March, 1956.

The results of an 805-mile (1300 km.) airborne magnetometer profile flown across Tunisia and Algeria, from Tunis to the west coast of Oran, across north-western Spanish Morocco and Tangier, and across south central Portugal to Lisbon are presented. The general geology of the zone over which the profile was flown is shown with the magnetic variations. Depth, structural and rock type interpretations have been made from the magnetic control. The depth values are believed to be high due to angle of the flight line with respect to the probable maximum gradient of the magnetic anomalies. However, depth values are given in all of the basins of possible interest.

(Author's Abstract).

143. *Prospecting by Airborne Magnetometer.*
P. A. Rankin, Mine & Quarry Engnrg., No. 8, pp. 64-70, February 1955.

Aeromagnetic surveying is very speedy in the search for oil and mineral ores. In the example discussed, the detecting device is housed in the tail of the aircraft and the recording equipment is situated in the cabin. The aircraft flies between 100-200 m. high, the course is fixed by radar, and continuous photographs of the area are taken.

Aeromagnetic surveys have assisted greatly in the geophysical surveys of Papua, East Africa and Assam. The iron ores of Malaya, and iron ore and other ores of the Philippines have also been investigated by this method.

144. *Annual Variation of the Magnetic Elements.*
R. P. W. Lewis, D. H. McIntosh & R. A. Watson, J. Geophys. Research, Vol. 60, No. 1, pp. 71-74, 1955.

Annual variations of the horizontal intensity (H force) were computed for a number of stations, using values for magnetically quiet days where available. These are expressed in terms of Fourier components. Differences found between one pair of stations suggest that the annual variation arises from local as well as world-wide influences.

(Author's Abstract).

145. *Normal Field and the Average Secular Variation of the Magnetic Elements in Sicily.* (In Italian).
M. Giorgi & F. Molina, Ann. Geofis., Vol. 7, No. 4, pp. 521-537, 1954.

146. *Magnetic Susceptibility Measurements in West Texas and Southeast New Mexico.*
P. T. Flawn, Tulsa Geophys. Soc., Vol. 1, pp. 55-58, 1953.
The magnetic susceptibility of 96 samples of Pre-Cambrian cores and cuttings from the basement rocks of west Texas and southeast New Mexico are determined. The results are tabulated.

147. *A Bibliography of Papers Having Experimental Data on the Magnetic Susceptibility of Minerals and Rocks.*
H. M. Mooney, Tulsa Geophys. Soc. Proc., Vol. 1, pp. 59-61, 1953.

148. *Magnetic Anomalies in Wilson and Woodson Counties, Kansas.*
W. W. Hambleton & D. F. Merriam, Kansas Geol. Survey Bull., No. 114, Pt. 3, pp. 113-128, 1955.

149. *Magnetic Surveys Over Serpentine Masses, Riley County, Kansas.*
K. L. Cook, Mining Engineering, Vol. 7, No. 5, pp. 481-488, 1955.

150. *Anomalous Direction of Magnetization of the Rhön Basalts.* (In German).
R. Dixius, Geofis. Pura e Appl., Vol. 28, pp. 109-148, 1954.

151. *Gravity and Magnetometer Surveys for Chromite Ore Deposits in Turkey.*
K. Ergin, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, sec. 9, Fasc. 9, pp. 123-130, 1954.

152. *Practical Applications of Magnetic Methods in Oil Finding.*
J. Affleck, a paper read at the 9th Annual Midwestern Meeting of the S.E.G. at Fort Worth, Texas, March 1956. (Not yet published).
This paper discusses the usefulness of the magnetic method in an exploration programme. The sources of magnetic anomalies and basement characteristics are described, and illustrations show typical profiles over basin and uplift zones and samples of magnetic data and derivatives over known structures.

MAGNETIC — INSTRUMENTAL

153. *A Simple, Sensitive, Saturated-Core Recording Magnetometer.*
V. B. Gerard, J. Sci. Instr., Vol. 32, No. 5, pp. 164-166, May 1955.
A versatile saturated-core recording magnetometer, designed to meet a number of geophysical uses, is described. Comparisons with a standard magnetic observatory variometer show that the large amount of negative feedback used keeps the instrument very stable. It has good high-frequency response, and is simple to manufacture and service.

(Author's Abstract).

154. *Patents.* Abstracts in Geophysics, Vol. 20, No. 3, p. 688, July 1955.
U.S. 2, 702, 882. 22 Feb., 1955. A non-oriented total-field magnetometer.

155. *A Recording Magnetic Variometer.*
J. H. Meek & F. S. Hector, Canadian J. Phys., Vol. 33, No. 7, pp. 364-368, July 1955.
The circuit and detecting head of an electronic recording magnetic variometer, which will give continuous and immediately observable values of variations of magnetic field as small as 10^{-5} oersted, is described.

156. *An Electronic Magnetometer.*
B. G. Cragg, J. Sci. Instr., Vol. 32, No. 10, pp. 385-6, October, 1955.
A probe unit containing a miniature c.r.t. is brought into the field to be measured, and the resulting deflection of the electron beam is automatically compensated by a voltage applied to the electrostatic deflecting plates. This voltage is proportional to the magnetic field for steady fields and for fields changing at not more than 10 kc/s. Using standard components an output of 12.5 v/oersted is obtainable with a drift of about 1 mV/min. The smallest field measurable in thus 10^{-4} oersted.
(Author's Abstract).

157. *Patents.* Abstracts in Geophysics, Vol. 21, No. 1, p. 192, January 1956.
U.S. 2, 713, 661. 19 July 1955. A phase-shift type magnetometer.

MAGNETIC — INTERPRETATION

158. *Modern Methods of Gravity and Magnetic Interpretation.*
S. Hammer, Proceedings of the 4th World Petroleum Congress, Section I, pp. 635.
Modern interpretation techniques in use under development, are reviewed and illustrated by selected maps and figures. These include "residual" and "second derivative" maps, "resolution", "continuation", "statistics" and "electronic computations". Underground observations to yield a third dimension in exploration are included.

159. *Interpretation of the Results of Magnetic and Gravimetric Surveys with the Aid of Modern Electronic Computing Equipment.*
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The fantastic speed with which modern electronic computors perform fundamental arithmetic operations opens unlimited possibilities for improving the scope and accuracy of technological computations. This paper discusses the use of electronic data-processing machines for the computation of the regional anomaly, derivative maps, and the continuation to various depths from a given observed anomaly map.

MAGNETIC — THEORY & RESEARCH

160. *A New Method of Measuring the Earth's Magnetic Field.*
G. S. Waters & G. Phillips, Geophysical Prospecting, Vol. 4, No. 1, pp. 1-9, March, 1956.
This paper describes the measurement of the earth's total magnetic field by a determination of the frequency of free precession around this field of the protons in a sample of water. The angular frequency of precession, ω, is related to the field 'F' by the relationship $\omega = \gamma_\rho F$ where γ_ρ is the gyromagnetic ratio of the proton.
A bottle of water is magnetized in a direction approximately at right angles to the earth's field, by passing a current through a coil, wound around the bottle. The current is switched off rapidly, leaving the magnetic moment vector to precess around the earth's field direction, inducing in the coil a small alternating voltage. This voltage is amplified and its frequency measured by means of a counter. The accuracy of measurement of the total field is estimated at ± 0.5 γ.

In addition to the total field value, the form of the signal voltage contains information on the field gradient across the sample.

Simple theory, experimental details and results are given.

(Author's Abstract).

161. *Line Spacing Effect and Determination of Optimum Spacing Illustrated by Marmora, Ontario Magnetic Anomaly.*
W. B. Agocs, Geophysics, Vol. 20, No. 4, op. 871-885, October 1955.

The airborne magnetometer data of the Marmora iron ore deposit at Marmora, Ontario have been used as an example to show the results obtained by the use of various line spacings ranging from one mile to one-quarter mile. The maps show how easy it is, in any type of geophysical survey, to miss a feature of economic value if the line spacing is too course.

(Author's Abstract).

ELECTRICAL

162. *Measurements of Variations of Potential Differences on the Earth.* (In Japanese).
N. Makino, J. Inst. Elect. Japan, Vol. 74, No. 8, pp. 949-956, Aug., 1954.

Electrical prospecting by the spontaneous polarization method becomes difficult when p.d.'s on the earth vary with leakage currents from electric railways. Measurements taken by means of galvanometers and a c.r.t. at three different sites show clearly that (1) the magnetitude of the variations $\underline{\smile\smile}$ 5-10mV/m; (2) variations show directional character; and (3) variations can be correlated with train movements. Use can be made of these variations during prospecting. Potential distribution due to the spontaneous polarization can be successfully separated from the variations by direct reading apparatus. Procedure for determining the potential distribution from the data is given.

(From Elec. Eng. Abstracts, B, October 1955).

163. *Some Notes Concerning the Wenner Configuration.*
E. W. Carpenter, Geophysical Prospecting, Vol. 3, No. 4, pp. 388-402, December 1955.

It is shown that three resistances can be measured for any four-electrode configuration, and a simple relation between them is derived. The Wenner electrode configuration is discussed and a further relation derived between the three apparent resistivities corresponding to the three resistances. The practical value of the resistance relation as a means of avoiding experimental errors is indidated. The actual values of the three apparent resistivities are determined for a number of simple problems and the possibility of having a negative apparent resistivity is illustrated. Examples of field tests are given in which the three resistances are measured. The method can be a simple way of distinguishing between effects of lateral and vertical resistivity variations.

164. *Theory and Application of a Dual Frequency Airborne Electro-Magnetic System.*
D. G. MacKay, A paper read at the Annual Meeting of the S.E.G. at Denver, Colorado, October 1955. (Not yet published).

The problems involved in inductive electromagnetic surveys from aircraft are reviewed and the relative merits of phase and amplitude measurement discussed Phase-measurement equipment operating on two independent frequencies is described, and the installation of the equipment in a PBY 5a aircraft illustrated.

A number of examples, taken from actual surveys, are given showing the method of presentation of the data, the interpretation placed upon various anomalies, and also something of the results achieved.

In conclusion, an opinion is expressed on the proper application of this type of airborne survey to modern mining exploration.

165. *Geoelectrical Structure Investigations in Jugoslavia and Austria.* (In German).
V. Fritsch, Geophysical Prospecting, Vol. 4, No. 1, pp. 24-36, March 1956.

Examples are given illustrating the application of geo-electrical methods to engineering problems in Austria and Jugoslavia. A large number of these examples deal with dam problems. In this field, resistivity methods are used for bedrock investigations, to check the efficiency of cement injections into the rock, and to investigate the seepage of water underneath the dam. In the building and maintenance of roads, resistivity methods are used for the detection of cavities underneath the roads. On the Vienna air port, a radio method was used for the same purpose.
(Author's Abstract).

166. *The Apparent Resistivity of an Inclined Plane Layer.* (In German).
A. Huber, Archiv Met. Geophys. u. Bioklim., Ser. A, Band 8, Heft. 1-2, pp. 95-112, 1955.

Starting from the rigorous representation of the electrical potential for a wedge the apparent specific resistance is derived for both a parallel and a normal direction of the measuring basis with regard to the output of an even inclined stratum boundary. Comparison of the resistance curves with the normal two-layers curves indicates possible errors in evaluating geo-electric soundings. Furthermore it is shown how the apparent specific resistance varies when an outcrop is being crossed with a horizontal sonde and how the direction of a stratum boundary can be determined by radial sounding. Finally, the theoretical bases for investigation of the influence of slopes on geoelectric sounding are developed.
(Author's Abstract).

167. *Geoelectric Measurements in Predominantly Argillaceous Zones. A Case of Stratification with Varying Resistivity.* (In Italian).
F. Mosetti, Indust. Min., Anno 5, No. 5, pp. 257-259, 1954.

This is a discussion of the shape of the apparent resistivity curves from measurements by the Wenner method over different geologic structures, such as a homogeneous medium with constant electric resistivity, a medium composed of two horizontal layers, each with constant resistivity, a medium of three or four similar layers, and a layer with resistivity continually increasing with depth.

In the last the resitivity curve must be a straight line at an angle of 30° to 40° with the abscissa axis. With a set of such graphs computed for different variations of resistivity, it is possible to interpret the field measurements.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

168. *Telluric Study in the Basin of Hodna.* (In French).
Soc. Nat. de Recherches et d'Expl. des Petr. en Algerie & M. Bouchon, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 9, Fasc. 9, pp. 231-243, 1954.

169. *Some Results of Geoelectric Surveying During* 1953. (In Italian).
A. Manfredini, Ser. Geol. Italia Boll., Vol. 75, Fasc. 2, pp. 969-971, 1954.

A preliminary report on geoelectric surveys carried out in the Pontine lowland, at Monte Circeo, and at Spoleto. Several sources of underground water were discovered.

170. *The Application of a Three-Element Model to the S.P. and Resistivity Phenomena Evinced by Dirty Sands.*
J. G. McKelvey, P. F. Southwick, K. S. Spiegler & M. R. J. Wyllie, Geophysics, Vol. 20, No. 4, pp. 913-931, October 1955.

A simple resistor model consisting of three elements in parallel and representing (a) an element of solution and conducting solid particles in series, (b) an element of the solid particles only, and (c) an element of solution only, explains satisfactorily the experimental relationship between the conducitvities of solutions used to saturate synthetic dirty sands and the conductivities of the saturated sands. The synthetic dirty sands consist of beds of ion-exchange particles.

The same model is applied to give a theoretical explanation of the potential differences between two different solutions when these meet in the interstices of a synthetic dirty sand; excellent agreement is observed between theory and experiment. It is found that both potentials and resistivities depend on the same geometrical parameters. Hence they can be related to each other. The relationship is derived between the self-potential deflection and the resistivities of rock and invaded zone. It is compared to various formulae proposed by other investigators for interpreting logs in dirty sands.

Conductivities and potential differences across plugs of "synthetic dirty sands" containing oil have been measured. At high oil saturations the potential differences are almost as high as those across a solid membrane containing the same ion-exchange resin.

(Author's Abstract).

171. *A Low Frequency Electrical Earth Model.*
W. C. Pritchett, Geophysics, Vol. 20, No. 4, pp. 860-870, October 1955.

A general earth model is described which simulates the earth when excited by currents either conductively coupled to the earth by electodes or inductively coupled to the earth by loops. Consideration of model equations showed that a material with a resistivity of approximately 10^{-4} ohm-meters was desired for use in the model. Although suitable materials with this resistivity were not known, it was found that fine bronze wheel grindings held together by wax did have the required macroscopic resistivity. Using this model, surface measurements were made employing a modified Wenner spread "one mile" in length. Only minor anomalies resulted from a simulated salt dome "three-quarters of a mile" in diameter and "one-half mile" below the surface.

(Author's Abstract).

172. *Patents.* Abstracts in Geophysics, Vol. 20, No. 4, p. 947, October 1955.

U.S. 2, 708, 261.	10 May 1955.	Electrical prospecting system, utilizing a borehole in which an electrode is placed together with electrodes on the surface.

173. *Patents.* Abstracts in Geophysics, Vol. 21, No. 3, p. 854, July 1956.

U.S. 2, 730, 673.	10 Jan. 1956.	A d-c e.m. prospecting system in which the field between two electrodes is measured.
U.S. 2, 731, 596.	17 Jan. 1956.	An e.m. prospecting system whose exciting- and pickup-coils are in series with an impedance network.
U.S, 2, 735, 980.	21 Feb. 1956.	An e.m. prospecting method in which a square wave is passed between electrodes.

174. *Geophysical Exploration by the Induction Method.* (In Russian).
A. G. Tarkhov, Moscow, Gosgeoltekhizdat, 96 p., 1954.

A treatise on the e.m. induction method of mineral exploration. Four chapters deal with the physical foundation of the method, field methods and instruments, disturbing effects and the application of the method and examples of its successful use.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

175. *Telluric Currents as a Geophysical Investigation Method and the Possibilities of their Practical Application in the German Democratic Republic.* (In German).
G. Porstendorfer, Geologie, Vol. 4, No. 3, pp. 347-348, 1955.

Telluric current surveying is presented as a reconnaissance method, the prelude to a seismic survey. Telluric methods, in fact, have sometimes succeeded where seismic methods have failed at greater depths, due to inhomogeneities in the cover.

176. *The Determination of a Conductive Body by Electrical Prospecting Methods.* (In Russian).
S. V. Shalayev, Akad. Nauk SSSR Izv. Serv. Geofiz., No. 5, pp. 468-474, 1955.

Many ore bodies are good conductors of electricity, much better than the surrounding formations, so that their boundary surface can be considered as an equipotential surface. To locate such bodies, Shalayev uses potential theory and determines the values of the potential function in the lower semispace as the analytical continuation of the potential function which is determined from values on the earth's surface. Thus the assumption is made that the potential function is harmonic inside the sphere S of radius r; and if harmonic, this function can be uniquely determined from its values and the values of its normal derivatives on the circle cut by the sphere S on the earth's surface. It can be proved that on the earth's surface the normal derivatives are all zero, which makes the solution possible. By applying the theory of the complex variable, a method is derived for determining the upper surface of the ore body, but its lower boundary surface remains unknown.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

177. *The Valuation of the Oil-Bearing Potential of Reservoirs Characterised by Low Specific Resistivity.* (In Russian).
R. V. Yudkevich, Prikladnaya Geofiz., Vol. 11, pp. 63-71, 1954.

Oil-bearing rocks may have an electrical resistivity 50 times that of a water-bearing layer. The oil-bearing properties of a layer may be determined from the ratio of its resistivity when oil-filled to its resistivity when water-filled. A high ratio indicates high probability of the layer being petroliferous. However, a low ratio layer can prove to be oil-bearing in certain conditions, as when the layer consists of bands of oil-bearing sands and water-satured clays together. A spontaneous potential curve would indicate such stratification.

178. *A Tri-Potential Method of Resistivity Prospecting.*
E. W. Carpenter & G. M. Habberjam, Geophysics, Vol. 21, No. 2, pp. 455-469, April 1956.

This paper describes a method whereby three resistances are measured for a four electrode configuration, and relations between these three resistances and their corresponding apparent resistivities are derived. The practical application of the resistance relation as a means of detecting observational and instrumental errors is indicated. The concept of apparent resistivity is examined and by means of examples it is shown that the apparent resistivity can take negative values. Finally, the possibility of using the triple resistivity method as a means of distinguishing between the effects of lateral and vertical resistivity changes on depth probes is discussed.

(Author's Abstract).

179. *The Determination of the Long Dimension Conducting Ore Bodies.*
A. R. Clark, Geophysics, Vol. 21, No. 2, pp. 470-478, April 1956.

A solution of Laplace's equation in prolate spheroidal co-ordinates has been used to show that the resistivity profile obtained, when one current electrode is in the conducting body, may be used to obtain an estimate of the extent of the body along the long axis. The theoretical and experimental curves from a dipping conductor are compared.

(Author's Abstract).

GEOCHEMICAL

180. *Near-Surface Hydrocarbons and Petroleum Accumulation at Depth.*

L. Horvitz, Mining Engineer, Vol. 6, No. 12, pp. 1205-1209, 1954.

This paper describes how natural gas and oil deposits may be found by chemical analysis of near-surface soil samples. This method is being used in the oilfields of Texas. The results of Mauwel and Hastings (1946) and Harris and Galveston (1952) are discussed. The samples are taken in producing wells at depths of 8-12 feet.

It is demonstrated how the deep petroleum deposits are accumulated. Drill-cores from near-surface down to the deep deposits are analysed and comparisons made with the results from drill-cores of unproductive areas.

181. *Geochemical Prospecting Research Centre at the Royal School of Mines, Imperial College of Science and Technology.*

D. Williams, Bull. Inst. Min. Metal., Vol. 64, No. 576, pp. 51-58, 1954.

The author describes his plan for a Geochemical Prospecting Research Centre in Great Britain, similar to the Central Institute in the U.S.A. The plan regards three departments of the Centre: field investigations, routine analysis, and analytical research. The operation of each department and their co-ordination is described.

The aims of the Centre are to establish standard geo-chemical methods and tests, and eventually to form a catalogue of the various types of deposits.

For the benefit of future operators in the British Empire, a questionnaire has been worked out whose answers should give a broad picture of favourable areas for geochemical exploration.

182. *Patents.* Abstracts in Geophysics, Vol. 20, No. 4, p. 951, October 1955.

U.S. 2, 710, 924.	14 June 1955.	A flourimeter which uses a source of ultraviolet light and a photomultiplier tube whose output is indicated by a microammeter.
U.S. 2, 711, 644.	28 June 1955.	Apparatus for determining and measuring the gas content of soil samples.

RADIOACTIVE

183. *Airborne Scintillation Counter Surveys.*

W. B. Agocs, Canadian Min. Metall. Bull., Vol. 48, No. 515, pp. 109-111, 1955.

The scintillation counter has bearly 100% efficiency in detecting gamma rays. The response of the instrument to a sudden variation in radioactivity of a surrounding medium is not instantaneous, but is a function of the time constant of the instrument. The optimum time constant is determined by the speed at which the instrument is moving and the areal extent of the radioactivity anomaly. The value of the measurements obtained may be increased considerably if the instrument is calibrated against an absolute source. The cosmic ray ionization effect on an airborne scintillation counter may be determined by taking readings over water-covered areas. The choice of flight elevation in making an airborne radioactivity survey must be a compromise between the requirements of: a safe flying altitude, a flight altitude low enough to increase the relative amplitudes of the useful anomalies over the background, or a flight altitude high enough to scan a wide swath with each traverse.

The term "anomaly" means a gamma radiation that is unexpectedly large for the type of rock and the field conditions with which it is associated. The sharpness and shape of the anomalies may be key characteristics. The correct interpretation of gamma-radiation anomalies must be aided by accurate estimations of the surface and near-surface weathering and solution effect. The effect of topography on gamm-radiation intensity may be as great as, or greater than, the radiation from an ore deposit.

(From Geophysical Abstracts 161, U.S. Geol. Survey).

184. *Scintillation—A Practical Approach to Oil & Gas Exploration.*
G. A. Haddad, Oil Forum, Vol. 10, No. 3, pp. 92-3, March 1956.

Analytical reports of the U.S. Geological Survey are quoted as showing that petroleum can contain as much as 100 gm. of uranium per ton, and connate waters up to 10 gm. per ton. The association of uranium with bituminous shales, asphaltic sandstones, and petroliferous limestones indicates that under certain geological conditions crude oil could serve as a distributing agent, and that the uranium could accompany the petroleum on its migration and final entrapment.

If, as seems likely, a definite genetic relationship does exist between uranium and petroleum and/or the petroleum source bed, the scintillometer can be used to detect gamma ray activity from the uranium series, and so locate a probable petroleum reservoir. The interpretation of such surface gramma radiation requires an established individual technique, and a consideration of many prevailing conditions such as barometric pressure, temperature, cosmic radiation, etc.

185. *Patents.* Abstracts in Geophysics, Vol. 20, No. 4, p. 947, October 1955.

U.S. 2, 712, 088.	28 June 1955.	A self-quencing Geiger-Müller counter, with a gas mixture of helium, isobutane, and butadiene.

186. *You Still Must Drill.*
M. M. Reiss, Oil Forum, Vol. 9, No. 12, pp. 430-432, Mid-November 1955 and Vol. 9, No. 13, pp. 509-511, December 1955.

In a two-part article the author, a distributor of geiger and scintillation counters, criticises some of the excessive claims that have been made for the uses of these and other radioactive instruments. Their greatest value lies in supplementing the findings of experiences geologists and geophysicists. Their proper application and effective use is discussed.

As a possible cause of radioactive haloes, the author suggests that oil and gas molecules trapped beneath an impervious cap rock may be squeezed from below the outer edges of the cap, and migrate upwards. The sulphur compounds released reduce the chlorides and sulphates in the waters of the covering formations to sulphides, and these dissolve radio-active minerals from the rock. The evaporation of the water at the ground surface leaves a residue of radium, usually re-oxidised to the chloride, as a halo roughly marking the outlines of the reservoir cap.

OTHER METHODS

187. *An Attempt at Application of Bacterial Strains as Indicators of Oil-Bearing Quality of the Given Area.* (In Polish).
A. Luchterowa, Bull. Polish Inst. Petr., Vol. 4, No. 4, 1954.

Some micro-organisms found in the soil convert gaseous hydrocarbons into carbon. 120 mixed cultures were tested at a depth of 3 metres on perforated plates; 24 of these thrived. The 24 were then tested in the laboratory with C_3-C_4 mixture at 4%, 0.4% and 0.04% concentration. Three mixtures were transplanted twice, and each time their incubation period shortened.

(From J. Inst. Petr. Abstracts, July 1955).

188. *A Microbiological Method of Prospecting for Oil.*
Dr. R. J. Strawinski, World Oil, Vol. 141, No. 6, pp. 104-115, November 1955.

A quantitative microbiological procedure is described which can used to detect hydrocarbon gases in subsoils. A composite soil sample mixed with nutrient medium is tested in a modified Sohngen gas culture unit for the consumption by the contained bacteria of oxygen and methane. The presence of large quantities of methane oxidising bacteria indicates the presence of gaseous hydrocarbons in the suboil, and this in turn indicates a possible subterranean oil deposit. The need for obtaining a representative sample in the field as well as in the laboratory is emphasized; and proper preservation of the sample is essential. The test period can be substantially shortened if the soil culture units are agitated during incubation. The effect of inoculum size on completion time is shown to be a linear function of the logarithm of the number of organisms originally present.

189. *Petroleum Exploration with Radio Waves.*

F. W. Kelly, Petroleum Engineer, Vol. 27, No. 6, pp. B. 40-57, June 1955.

The report, in two parts, discusses first the use of radio in prospecting for structures. The theory of the method and the equipment necessary are outlined, and it is concluded that the method has several distinct advantages, the most important being that continuous recording is possible, making for high speed operation at low cost. Geological faults that might be missed by seismic methods can be picked up by radio prospecting.

The second part discusses the direct location of oil accumulations by means of the "Radoil" technique. So far, oil boundaries at a depth of 9,000 feet have been satisfactorily traced by this method.

A SMALL-SCALE FIELD INVESTIGATION OF MOTION NEAR THE SOURCE *)

BY

R. G. MASON **)

ABSTRACT

A seismic field investigation on a reduced scale is described. A falling weight was used as the source of energy, with a recording system which permitted the display on a cathode ray oscillograph of two dimensional pictures of ground displacement in the vertical plane containing the source. These permit a quantitative study of the magnitude and direction of displacement and of the instantaneous velocity of motion.

INTRODUCTION

An understanding of the physical processes of seismology can be gained only through controlled experiments under conditions both simpler and better known than those generally encountered in earthquake seismology or seismic prospecting. Full-scale experiments in the field have contributed little to the problem. Energy considerations dictate the use of explosive sources, which lack refinement of control and produce disturbances of inconveniently low frequency for analysis by conventional methods, but the most serious weakness of field experimentation is the difficulty of appraising the medium.

In recent years investigators have turned to model experiments in the laboratory which offer the particular advantage that both the geometry and, in principle at least, the elastic properties of the medium are under the control of the investigator. However, the scaling down of wavelengths, perhaps by a factor of a thousand, and the corresponding scaling up of frequencies, since materials suitable for experiment propagate with velocities of the same order as natural formations, introduces other problems. The requirements of a measuring device, namely the ability to respond to steep fronted pulses and small physical dimensions relative to the wavelength, become difficult to satisfy. Furthermore, laboratory techniques for producing pulses of simple shape with controlled directivity are not all well developed. For these reasons model seismology has not advanced beyond qualitative demonstrations of simple phenomena.

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*) Presented at the Ninth Meeting of the European Association of Exploration Geophysicists, held in London, 7-9 December 1955.

**) Imperial College of Science and Technology, London.

This paper is concerned with a third approach to the problem, a field investigation on a reduced scale. The advantages of small-scale field experiments are that the selection of a suitable medium of sufficient extent becomes correspondingly easier, the smaller energy requirement permits the use of a more controllable source than the dynamite explosion, and scope exists for the construction of measuring equipment of a convenient size and acceptable performance. In the work described a falling weight was used as the source of energy, with a recording system which permitted quantitative measurement and the display of two-dimensional pictures of ground displacement on a cathode ray oscillograph.

THE SOURCE

A preliminary investigation showed that a source of energy of about 500 to 1,000 ft.lbs. would be adequate for experiments up to the planned maximum range of 300 feet. This was provided by a 100 pound weight which was released electrically and allowed to fall through a maximum height of ten feet into a shallow hole.

From the classical work of Lamb (1904) it may be assumed that the frequency of the disturbance produced by a falling weight will be a function of the duration of the impact. The problem of two elastic spheres in collision has been investigated by Hertz (1896) who showed that in the limiting case of the impact with velocity v of a spherical body of mass m and radius r on the plane surface of an elastic body of infinite mass, the duration τ of the impact is given by:

$$\tau = k(m^2/vr)^{1/5}$$

where k is a constant involving the elastic properties of the bodies. It is reasonable to suppose that the frequency of the disturbance produced by a falling weight can be controlled by adjustment of the variables m, v and r.

The possibility of such control was examined in a series of experiments involving weights ranging from 50 to 300 pounds and two to five inches in radius, dropped from heights of between three and nine feet. Observation of the periods at five feet and at one hundred feet of what were later demonstrated to be P and S, and Rayleigh, phases respectively, varying each of the parameters in turn, showed that, although changes in period of the correct sign occurred, the total variation was limited to a range of about ± 7 % about the mean value, compared with a predicted ± 40%. This discrepancy probably arises from non-elastic behaviour of the medium around the point of impact. It was concluded that within the limitations of the experimental arrangement little useful control could be exercised over frequency and all subsequent experiments were performed with a one hundred pound weight four inches in radius. The lowest frequencies produced were about 35 c/s, which is therefore the lowest frequency which the measuring system must be able to handle.

An important consideration with any source is its ability to produce similar disturbances under identical experimental conditions. A comparison of records produced under such conditions showed a remarkable similarity of wave form and amplitude, except for about one in five failures. These were usually quite easily recognized and, from the abnormal airborne sound produced at impact, were judged to be due to imperfect release of the weight. Otherwise amplitudes of successive disturbances agreed to within about ± 5 %.

The Measuring System

The measuring system followed the conventional geophone/amplifier/oscillograph pattern but incorporated several novel features. It comprised a two-component 8 c/s geophone connected to a double-beam cathode ray oscillograph through identical direct coupled amplifiers. Thus the source of much of the distortion associated with standard equipment was eliminated. Integrating circuits built into the amplifiers enabled records of displacement to be obtained and these were displayed in one of two ways, either separately on the two beams of the oscillograph or as two-dimensional pictures of ground displacement, utilizing the two axes of one of the beams.

The two-component geophone was constructed from commercial moving coil geophones mounted one vertically, the other horizontally, in a case four inches in diameter and eight inches high, and weighed 18 pounds. The natural frequency of the instruments was reduced from 35 c/s to 8 c/s by replacing the 'spider' type springs with weaker springs cut from beryllium copper. A problem arose with the vertical unit. As a fundamental consequence of reducing the frequency the depression of the springs under the load of the moving coil was increased from a negligible value to about 4 mm and demanded major re-design of the suspension. This was avoided by pre-stressing the springs in the annealing process so that under load they became approximately flat. The geophones were further modified by re-winding the coils with a larger number of turns of finer wire, thus increasing their sensitivity and impedance and eliminating the need for input transformers to the amplifiers.

The geophones were calibrated by weight lifting experiments and by examining their response to a constant current of variable frequency. They were found to produce an output of 0.6 volts/cm/sec at their natural frequency of 8 c/s, rising to about 0.98 volts/cm/sec for frequencies above 35 c/s. Phase distortion was more serious, representing a lag of 20° at 35 c/s and 10° at 80 c/s.

Since the two components were to be capable of quantitative comparison, particular care was taken to match the two geophones, both as regards sensitivity and frequency characteristics. At frequencies above 35 c/s their sensitivities agreed to within better than ± 2 % and the phase difference between the two instruments was less than 2°.

The amplifiers, based upon a circuit described by S. E. Miller (1941), were characterized by a voltage gain of 50,000, flat response and zero phase shift up to several hundred cycles and almost complete absence of drift. The integrating circuits were based on the well-known principle of charging a large capacity condenser through a high value resistance, except that the low frequency characteristics were improved by replacing the resistance by an amplifier triode with positive feedback. At 35 c/s the integrator produced a phase lead of 3° and the gain was 5 % less than unity. Since the output of the geophones lagged by 20° behind the motion of the ground, integration effected a slight improvement in the overall phase response but worsened the amplitude characteristics. The relationship of integrator output to geophone displacement, without amplifiers, is shown in Figure 1.

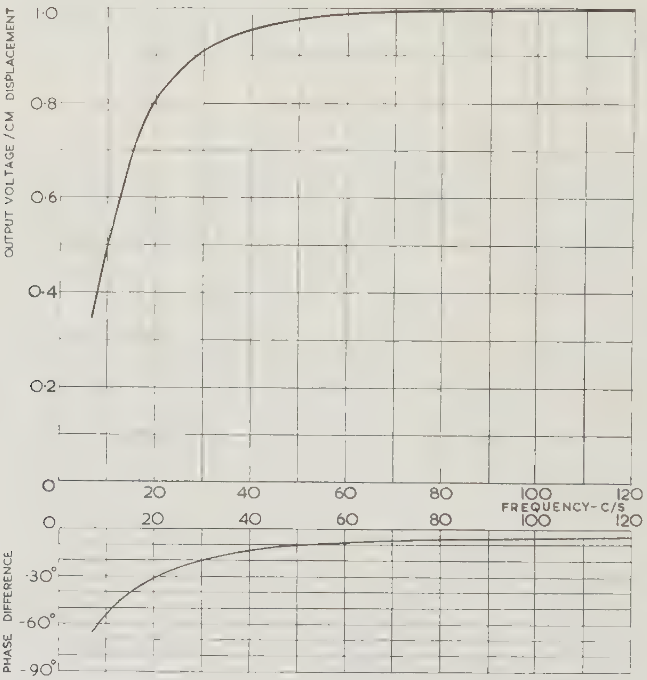


Fig. 1. Relationship of integrator output to geophone displacement

The oscillograph was provided with built-in D.C. amplifiers, an electronic beam-switching circuit which enabled the beam to be switched on an off by the application of external voltages of appropriate amplitude and sign, and a variable speed moving-film 35 mm camera which was run at a speed of 12 inches/sec for the double-trace records. Its sensitivity was such that, using the built-in amplifiers, an input of one volt produced a screen deflection of one cm. Thus with the external amplifiers and integrators the maximum ground-to-screen magnification was 50,000. Since the camera effected a reduction of 2.87 : 1 between screen and record the maximum overall ground-to-record magnification was about 17,500.

The beam-switching facility of the oscillograph was exploited to provide a method of recording the time of origin of the shock and to apply time marks to the records. A geophone buried close to the point of impact was connected to a circuit which, when the output of the geophone exceeded a pre-determined value, applied the voltage necessary to switch on the beam. Thus the commencement of the record coincided with the time of initiation of the shock. The arrangement functioned with an uncertainty of less than ± 10 microsecs. Time marks were provided by a 100 c/s reed built into a circuit which produced $\frac{1}{2}$ millisec breaks in the traces, at 10 millisec. intervals.

The overall sensitivity of the system was adjusted and measured by means of a 40 c/s oscillator with calibrated output which was applied to the inputs of the amplifiers in place of the geophones. For two-dimensional presentation the two channels were matched by applying the same output to both and adjusting the x-component amplifier to produce a trace inclined equally at 45° to x- and y-axes. This could be done with an accuracy of about ± 1°, representing an error of ± 4 % in amplitude.

The Field Experiments

The most suitable formations for experiment are the recent sediments. Macroscopically each formation is relatively uniform in composition and where stratification exists it is more or less horizontal. A site was chosen where about sixty feet of Bagshot Sands rest upon a considerable thickness of London Clay. The area was covered with one or two feet of Plateau Gravel and the water table was believed to occur at a depth of about forty feet.

The general arrangement of the equipment is shown in Figure 2. A hole about two feet deep was dug at the source so that the weight could fall on to undisturbed rock and the beam-switching geophone was buried at the bottom about a foot from the point of impact and in line with the observation points. To correct for the time taken for the disturbance to reach this geophone, all distances were measured from it. The two-component geophone, oriented with a maximum error of ± 2° in each direction, was buried firmly at a depth of about two feet. A trial experiment was carried out at each distance to determine the most appropriate sensitivity and the two channels were adjusted to this value.

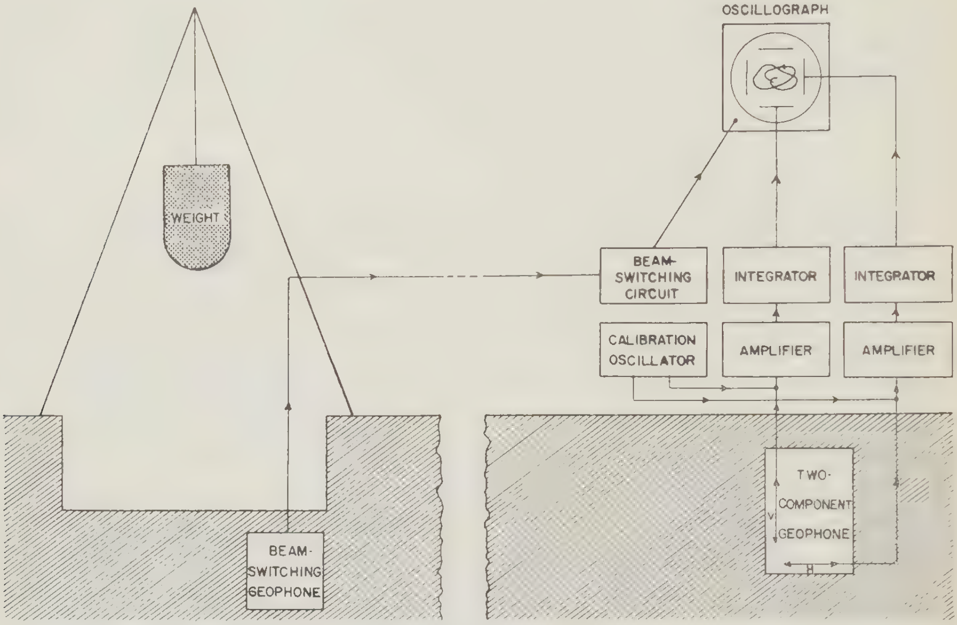


Fig. 2. The field arrangement

THE STUDY OF PROPAGATION

Separate records of vertical and longitudinal components of displacement were obtained at twenty foot intervals from a distance of twenty feet up to three hundred feet from the source. These have been assembled into one diagram, Figure 3, from which travel times have been picked and plotted and straight line time-distance curves fitted by the method of least square, Figure 4. The lines P, S and S' represent first arrivals in the longitudinal and vertical directions and the pairs of lines R1-R4 correspond to peak values of the largest displacements upwards, and away from the source, respectively.

Two-dimensional records of displacement in the vertical plane containing the source were also obtained at each distance and are reproduced in simplified form in Figure 5. The refinement of the two-dimensional method of presentation is illustrated by the larger scale reproduction of the 140 foot record in Figure 6, which shows also a record obtained ten feet from the source. These records permit quantitative study of the magnitude and direction of displace-

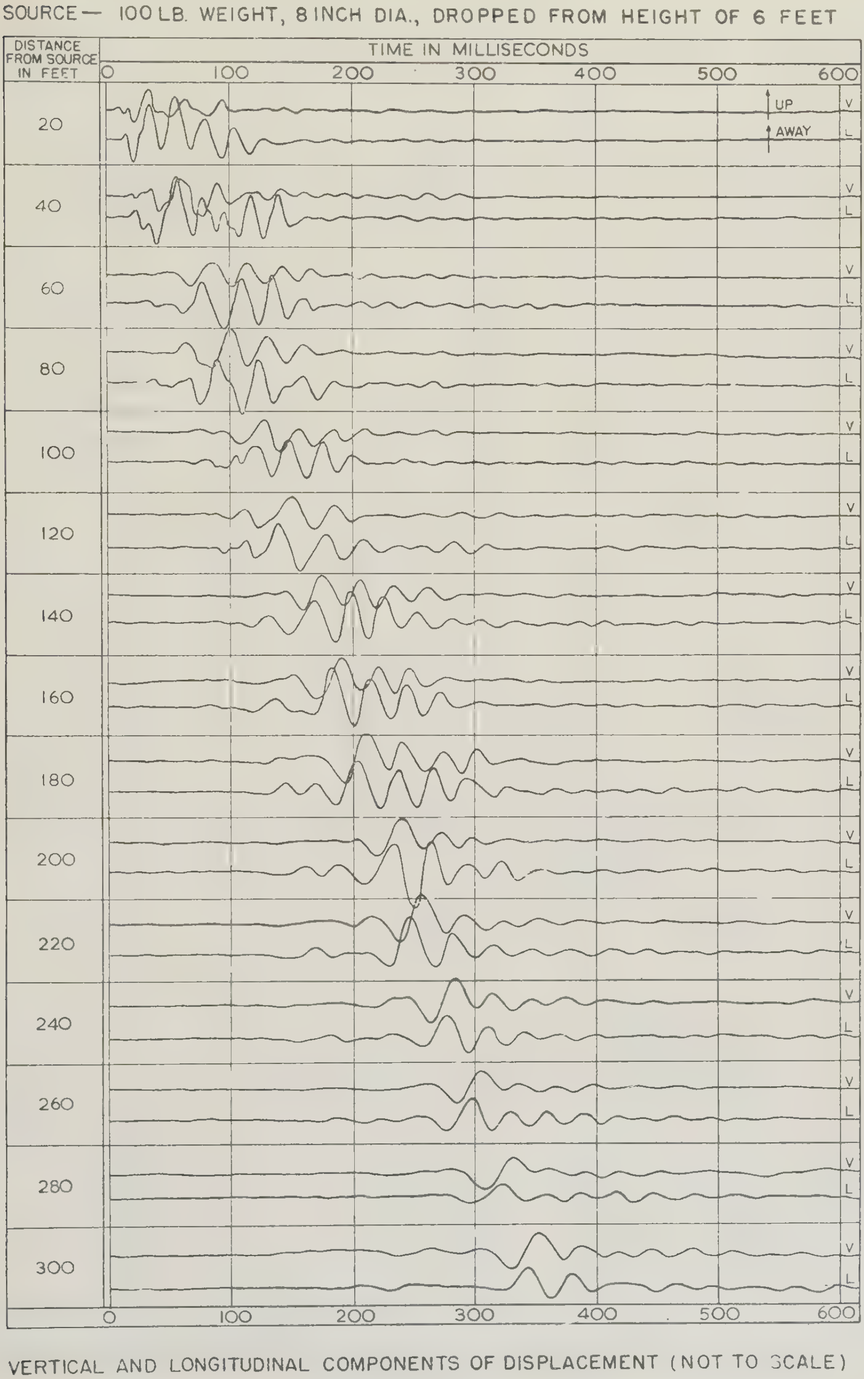


Fig. 3. Vertical and longitudinal components of displacement at distances between 20 and 300 feet from source

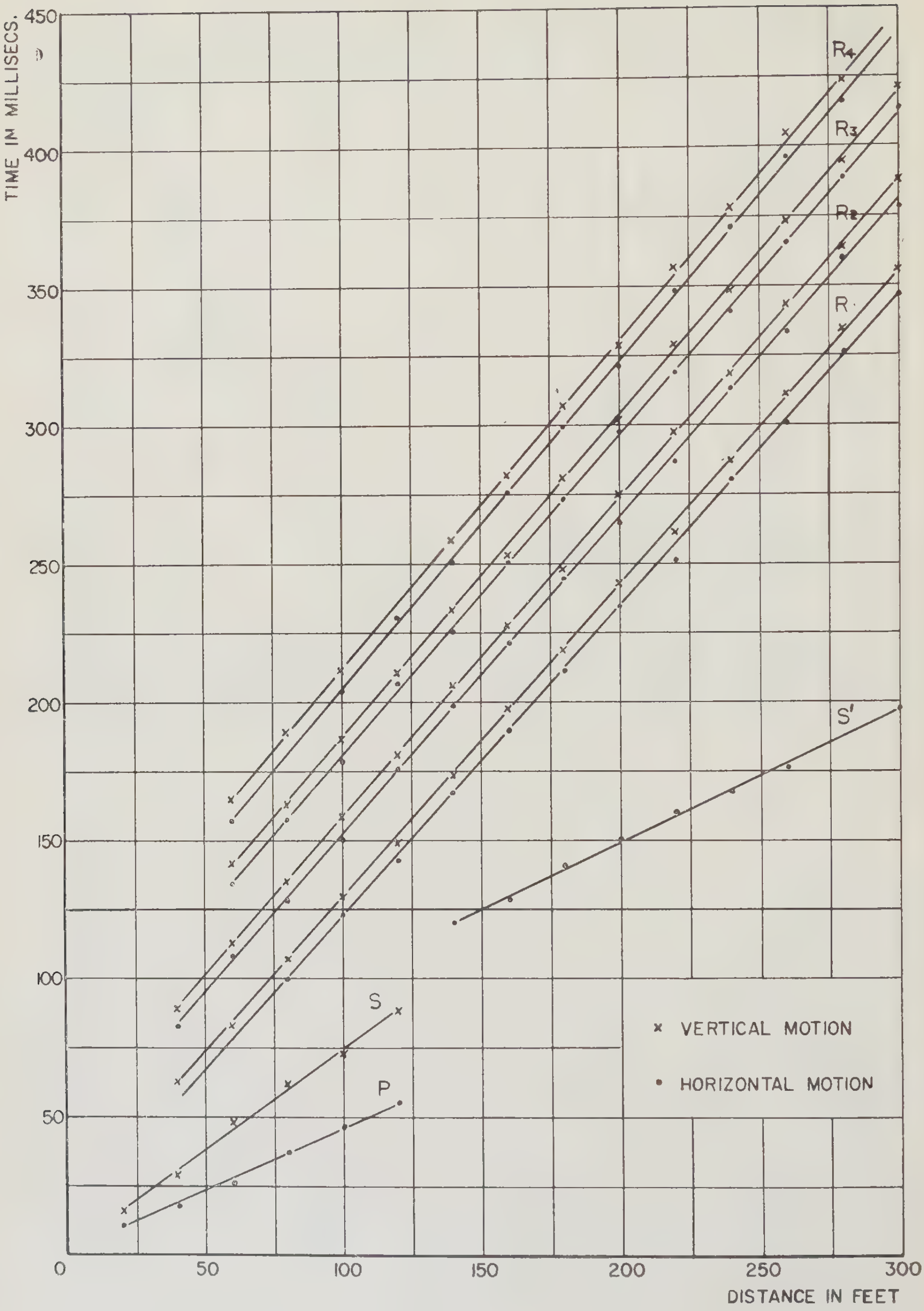


Fig. 4. Time-distance curves

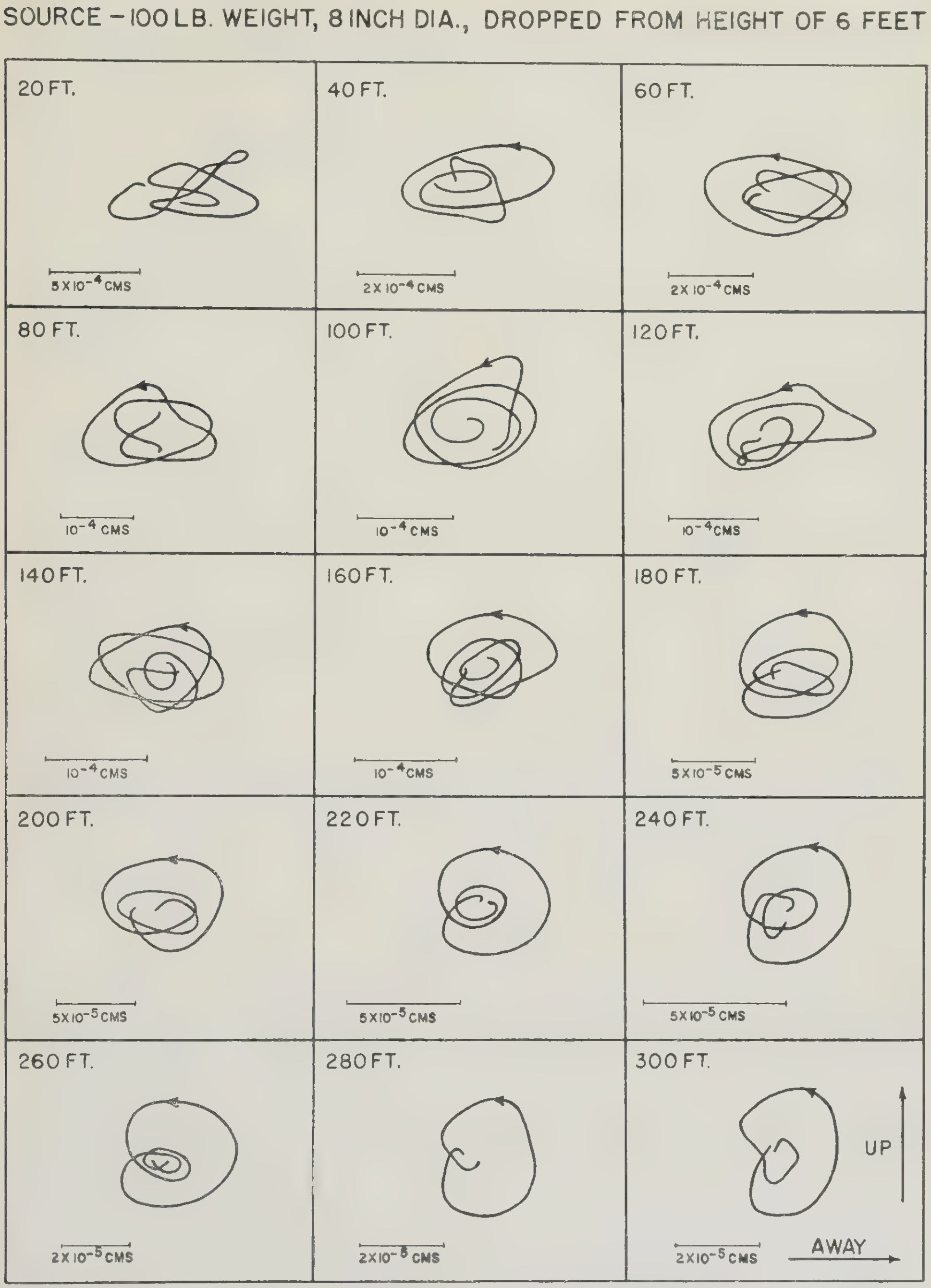
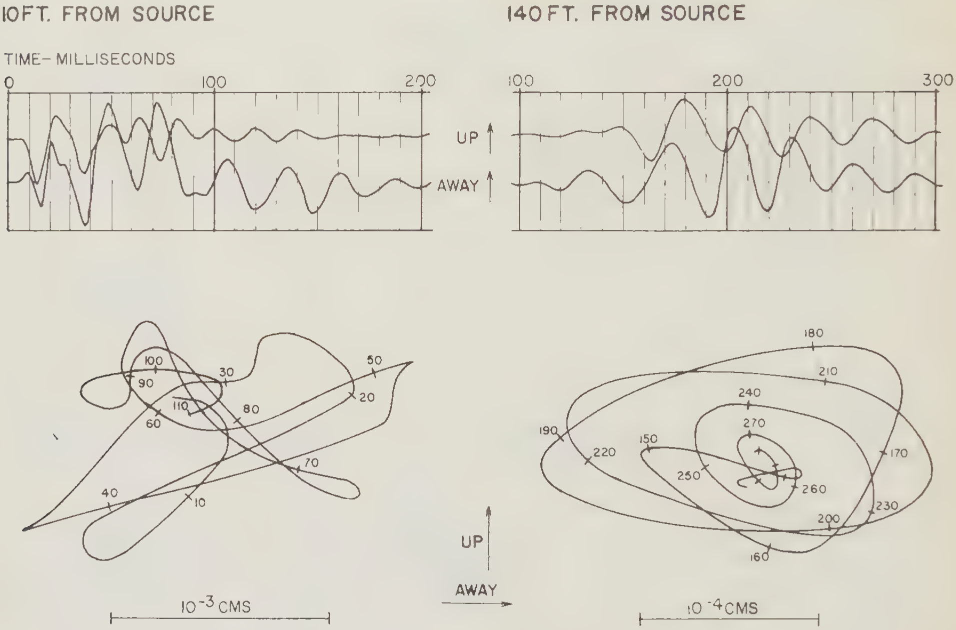


Fig. 5. Two-dimensional records of displacement at distances between 20 and 300 feet from source

ment and of the instantaneous velocity of motion. Thus the maximum particle velocities at the two distances may be seen to be about 2 mm/sec. and 0.2 mm/sec. respectively.



10FT. FROM SOURCE

140 FT. FROM SOURCE

SOURCE – 100 LB. WEIGHT – 8 INCH DIAMETER – DROPPED FROM HEIGHT OF 6 FEET

Fig. 6. Showing details of displacement at 10 and 140 feet from source

BODY WAVES

The first disturbance to arrive at points up to 100 feet from the source had the characteristics of a *P*-wave, that is the major displacement was in the longitudinal direction. Thus in the ten foot record of Figure 6 the initial motion is away from the source and inclined slightly downwards. Beyond 100 feet the amplitude of the *P*-wave became so small in relation to the amplitude of later arrivals that it could no longer be identified with certainty. From the time-distance curves its velocity was found to be 2,170 feet/sec. The next arrivals on the same records were predominantly vertical and were identified as *S*-waves. On the ten foot record the downward swing of the curve above the 10 millisec. mark corresponds to the onset of the *S*-wave. The *S*-wave velocity was found to be 1,370 feet/sec. giving a $P : S$ velocity ratio of 1.59, rather less than the theoretical value $\sqrt{3}$ for Poissons ratio $\sigma = \frac{1}{4}$.

At distances beyond 140 feet the first arrival was characterized by a large movement in the longitudinal direction, accompanied in most cases by a small displacement in the vertical direction. From the time-distance curves it was found to be a refracted wave travelling in the lower medium with a velocity of 2,070 feet/sec. Its velocity relative to those of the P- and S-waves in the upper medium, slightly less than the former and 1.5 times the latter, suggests that it is an S-wave. It is interesting to note that its amplitude is very much greater than the amplitudes of the direct P- and S-waves at the same distance. From the intercept of the S curves the depth of the refracting interface was found to be 47 feet, which is about the expected depth of the water table.

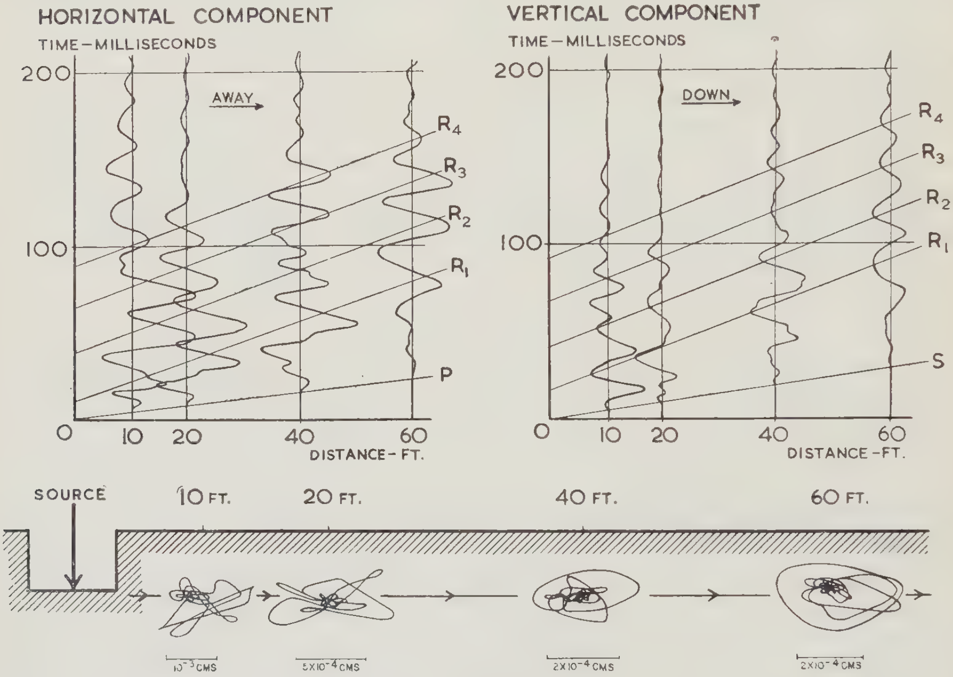
Gassman (1951) has investigated the theory of the propagation of elastic waves through a model which closely resembles the unconsolidated Bagshot Sands. Considering a hexagonal close array of spherical particles of granite packed under their own weight, both dry and filled with water, he showed that the ratio of wet and dry velocities should lie between about 4 at the surface and 1.4 at depth. Thus the observed value, 1.5, lies within the predicted range.

SURFACE WAVES

At 40 feet from the source, and beyond, the largest amplitudes were associated with motion having the characteristics of Rayleigh waves, that is an elliptical motion in a retrograde sense. The elliptical nature of the motion is demonstrated quite clearly in the two-dimensional records of Figure 5 and the retrograde sense of the rotation follows from the 90° lag of the upward behind the longitudinal displacement away from the source evident in the records of Figure 3 and the time-distance curves $R1 - R4$. From the slope of the latter the mean velocity of the Rayleigh waves was found to be 865 feet/sec, which compares with a theoretical value of 1,260 feet/sec. for $\sigma = \frac{1}{4}$, and the mean wavelength was found to be about 25 feet. There is evidence of dispersion in the form of a decrease in the periods of successive cycles at a given distance and an increase in the period of a given cycle with distance. Thus the periods of the first three cycles at 75 feet are30, 28 and 24 millisecs. respectively, increasing to 34,32 and 29 millisecs. at 300 feet.

A curious feature of the records is the appearance of several complete cycles of typical Rayleigh wave motion, not only at the greater distances, where they might arise from dispersion, but as close as 40 feet from the source. Between 140 and 180 feet four cycles of almost equal amplitude develop and these can be traced, with varying amplitude, over the whole range from 40 to 300 feet. The manner in which they arise can be understood more clearly by reference to Figure 7, which shows the separate components and the two-dimensional records for distances of 10, 20, 40 and 60 feet. The lines labelled $R1$—$R4$ are projections of the time-distance curves of Figure 4. Both components of *R*1 and *R*2 can be traced back to 10 feet with complete certainty, but there is some difficulty in positively identifying *R*3 and *R*4. Turning to the two-dimensional records, four cycles of approximately elliptical motion can be recognized at 60 feet and three at 40 feet, but close to the source the phase relationship deteriorates and the figures become less regular.

Thus the components of displacement necessary to produce several cycles of Rayleigh wave motion can be traced back to within half a wavelength of the source, though their initial phase relationship is not such as to produce regular elliptical motion. It is a striking fact that more than 1/10 sec. after initiation of the shock, movements that will contribute to the fourth and later cycles of the Rayleigh wave at 40 feet and beyond are still taking place within ten feet of the source.



7. Motion near the source

The quantitative nature of the observations enabled two other properties of Rayleigh waves to be studied, namely axial ratio and attenuation with distance. At the surface of a medium for which $\sigma = \frac{1}{4}$ the theoretical value of the ratio of vertical and longitudinal axes of the ellipse is 1.5 and this increases with depth, becoming infinite at a depth equal to 0.19 times the wavelength, where the horizontal component changes sign. Since the geophone was buried at a depth of two feet, or about 0.08 times the wavelength, the ratio should be greater than 1.5. The measured value of the largest ellipse at each distance was found to increase more or less regularly from 0.6 near the source to 1.3 at 300 feet. Thus although the ratio was increasing with distance, at 300 feet it was still rather less than the theoretical value.

As regards attenuation, since Rayleigh waves are propagated in two dimensions only, their energy density should vary inversely as the distance from the source and their amplitude inversely as the square root of distance. By plotting against distance the mean amplitude of the largest ellipse at each distance, on a logarithmic scale, the amplitude was found to vary approximately inversely as the distance and therefore more rapidly than predicted. Taking into account the change of axial ratio, the horizontal component decayed more rapidly than the vertical. Since the waves are dispersive, the treatment is arbitrary and it would have been better to have summed the energy of all the Rayleigh wave motion.

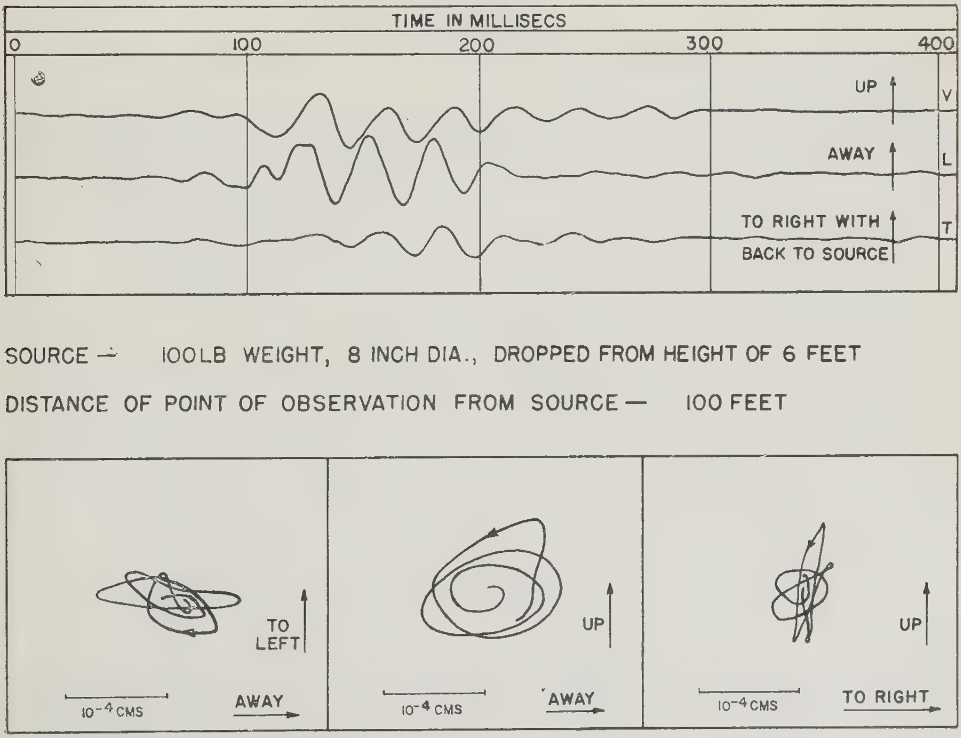


Fig. 8. Showing transverse motion at 100 feet from source

Transverse Motion

Transverse motion was investigated at one distance, namely 100 feet, with the aid of an additional horizontal geophone whose output was combined with the outputs of each of the other two geophones in turn to yield two-dimensional pictures of displacement in the horizontal and transverse planes. The results are shown in Figure 8. Appreciable motion occurred in the transverse direction, coinciding for the most part with the third and fourth Rayleigh wave cycles which were skewed round so that their major axes made an angle of about 30° with the direction of the source. However, from observations at one distance it is not possible to determine whether the transverse motion is an integral part of the Rayleigh wave or an independent phase.

Acknowledgements

The author wishes to thank Professor J. M. Bruckshaw of Imperial College for his helpful criticism and the British Petroleum and Shell Oil Companies for their financial support of the work.

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REPRESENTATION OF DEPTH-CONTOUR MAPS OF ARBITRARILY CURVED REFLECTION HORIZONS, INCLUDING REFRACTION OF RAYS, THREE-DIMENSIONAL CASE *

BY

E. GRAESER**, W. LODE***, and G. POTT***

Abstract

A method of constructing depth contour maps of arbitrarily curved horizons obtained from seismic reflection surveys is discussed. This method takes into account three dimensional refraction, avoiding the construction of seismic cross sections of any kind. It requires little work even if refraction at several horizons is taken into account. The multiple layer problem is traced back to the single layer case. Discontinuities in velocity are also taken into account.

Under favourable circumstances a preliminary general picture of the position of reflection horizons may be obtained by considering one seismic reflection profile only. A popular method of constructing such a profile from the recorded normal reflection times (i.e. reflection times at zero shooting distance) is the so called tangent construction method which assumes (not always correctly) the reflected rays to be in the plane of the profile. After adequate terrain corrections, the normal reflection times recorded at the shot points are multiplied by the instantaneous velocity which is assumed to be known. Circles whose radii are the distances thus obtained, are then drawn around the shot points. The envelope of these circles is approximated by means of common tangents to neighbouring circles. It then represents the intersection of the plane of the profile with the reflecting boundary plane.

The three dimensional form of the ray paths is taken into account by considering several intersecting profiles. In simple cases the 'true dip' can be determined geometrically at the points of intersection of pairs of seismic profiles. However, in the strict mathematical sense this is possible only if the reflecting interface beneath the shot point can be assumed to be plane. This special case has been treated in detail by J. Baumgarte (1955), who also suggests a method of construction. In practice this method is seldom applicable, as the construction involves a considerable expenditure of time. Besides in problems such as that shown in figure 1 it does not lead to a solution.

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*) Part of this paper was presented by W. Lode at the Tenth Meeting of the European Association of Exploration Geophysicists, held in Hamburg, 16-18 May 1956.

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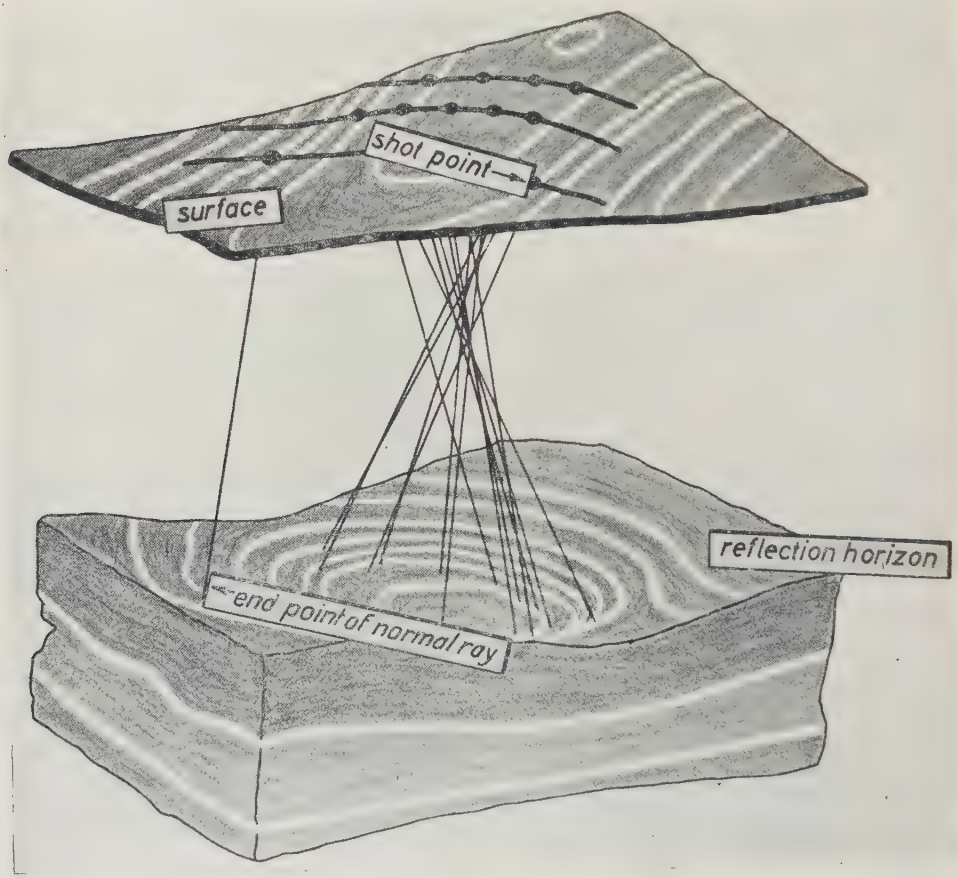

Fig. 1. Showing normal seismic paths in the single layer case.

Another method for the determination of interfaces with arbitrary curvature which has been given by M. Weber (1955), is an extension of the usual method for the construction of seismic horizons. This method is hardly applicable in routine work, since it requires seismometer spreads of considèrable length for horizons even at medium depths. Apart from this, it cannot be used when several reflecting horizons are present.

The present study differs from the above mentioned methods in that it presents an exact method for the construction of depth contour maps of arbitrarily curved horizons from observed normal reflection times. It takes into account the refraction of the rays in space when the overburden consists of layers having different velocities.

The method does not require the construction of seismic cross sections, but allows depth contour maps to be constructed rapidly and directly from normal depth* maps.

Since the strike and dip of the reflecting interface need not be taken into consideration when laying out the profiles on the earth's surface, they can be arranged along any kind of roads or field tracks in order to avoid damage to crops etc., unless subsurface conditions require a special layout.

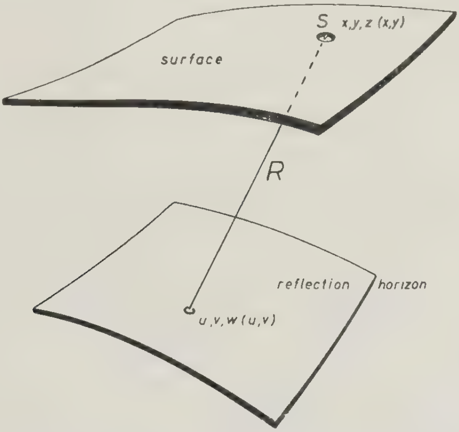

Fig. 2. Illustrating the notation used in the single layer case.

The problem of constructing the depth contour map from the corresponding map of normal depths, without constructing cross sections and taking into account refraction in space, will be solved accurately for the case of a constant overburden velocity. It will be shown that this problem can be solved by determining the point of intersection of a circle with a straight line.

Let the points on the surface of the earth (more precisely the surface of construction) be defined by the coordinates x, y, z (x, y), the x, y-plan may be sea level (Fig. 2). Let the reflecting interface be represented by the coordinates u, v, w (u, v), (u being the x-coordinate, v the y-coordinate, and w the z-coordinate). For every point x, y, z (x, y) of the earth's surface half the length of the seismic path is given by the equation

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*) The normal depth is obtained by multiplying half the observed normal reflection time by the velocity.

$$R = \sqrt{(u-x)^2 + (v-y)^2 + (w-z)^2}$$

when the overburden velocity is constant. This ray must be normal to the reflecting interface.

The reflecting interface can be considered as being built up of the end points (u, v, w) of all these normal rays. Consider a section of a sphere whose radius is the normal ray and whose centre is the shotpoint. Then the reflecting interface will be tangential to the surface of this sphere. Consequently, the reflecting interface must be the envelope of all these spherical sections and can be determined according to the general theory of envelopes. The equation of the spherical sections can be written as

$$H\,(u, v, w;\, x, y) = (u-x)^2 + (v-y)^2 + (w-z\,(x, y)\,)^2 - R^2\,(x, y) = 0$$

where x and y are the parameters defining the position of the centre. Differentiating this equation with respect to x and y, and equating the resulting derivatives to zero, we obtain

$$-\frac{1}{2}\frac{\partial H}{\partial x} = u-x + (w-z)\frac{\partial z}{\partial x} + R\frac{\partial R}{\partial x} = 0$$

$$-\frac{1}{2}\frac{\partial H}{\partial y} = v-y + (w-z)\frac{\partial z}{\partial y} + R\frac{\partial R}{\partial y} = 0$$

Writing

$$u-x = X;\; v-y = Y;\; w-z = Z$$

the equations become

$$X^2 + Y^2 + Z^2 = R^2$$

$$X = -\frac{\partial z}{\partial x}Z - R\frac{\partial R}{\partial x}$$

$$Y = -\frac{\partial z}{\partial y}Z - R\frac{\partial R}{\partial y}$$

We will have to determine the common point of intersection of the sphere and the two planes defined by these equations.

The equations may also be written in the form

$$\left(\frac{X}{R}\right)^2 + \left(\frac{Y}{R}\right)^2 + \left(\frac{Z}{R}\right)^2 = 1$$

$$\frac{X}{R} = -\frac{\partial z}{\partial x}\frac{Z}{R} - \frac{\partial R}{\partial x}$$

$$\frac{Y}{R} = -\frac{\partial z}{\partial y}\frac{Z}{R} - \frac{\partial R}{\partial y}$$

This means that two planes must be made to intersect and the resulting straight line must be made to intersect the unit sphere.

In practice if the coordinate system is chosen so that the x axis is tangent to the topographic contour lines, then

$$x = 0; \; y = 0; \; \frac{\partial z}{\partial x} = 0,$$

and

$$\frac{X}{R} = -\frac{\partial R}{\partial x}$$

thus the circle

$$\left(\frac{Y}{R}\right)^2 + \left(\frac{Z}{R}\right)^2 = 1 - \left(\frac{\partial R}{\partial x}\right)^2$$

has to be cut by the straight line

$$\frac{Y}{R} = -\frac{\partial z}{\partial y}\frac{Z}{R} - \frac{\partial R}{\partial y}$$

It is possible to solve this set of equations by means of simple mechanical or electrical devices*, each of which can solve this problem and find the required envelope without the use of graphs and the attendant uncertainties caused by interpolation.

In the case of a single reflector its position can be determined immediately from the above equations, as apart from the required $X\ Y\ Z$ all the variables can be measured.

R, $\frac{\partial R}{\partial x}$, and $\frac{\partial R}{\partial y}$ can be taken from the map of normal depths, z and $\frac{\partial z}{\partial y}$ from the topographical contour map.

If in a two-layer problem the first reflector is assumed to be a refracting interface, the solution is carried out in two stages:

1) After the normal reflection times corresponding to the second reflector have been multiplied by the velocity of the first sequence of layers and a map of normal depths has been drawn using these values, the three-dimensional position of the individual rays can determined as described above.

It is now easy to determine the points of intersection of these rays with the first reflecting horizon, by using the depth contour map of the first horizon.

2) Then the first reflecting horizon can be regarded as the new earth's surface (surface of construction) and the residual rays multiplied by the ratio of the average velocity of the first layers to the average velocity of the second layers can be regarded as new rays from the new earth's surface. (Fig. 3.)

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*) Patent has been applied for by *Prakla* in respect of these devices which have been constructed by the authors in cooperation with Dr.-Ing. habil *Vetterlein* and *von Jezierski*.

The two layer problem is thus reduced to a single layer problem with an arbitrarily curved ground surface.

Similarly the multiple layer case can be reduced to the single layer case.

The method developed by Baumgarte (1955) with sectionally plane surfaces and described as "Modification of Ficticious Echo Ray Paths", is a special case of the general problem of refraction at arbitrarily curved surfaces just described. The method described makes it possible to construct exact depth contour maps of arbitrarily curved reflectors from the results of seismic reflection surveys. Cross sections can be made from these maps in any positions considered useful from a geological point of view. The method also helps to solve, with the minimum amount of work, any problem arising in practice.

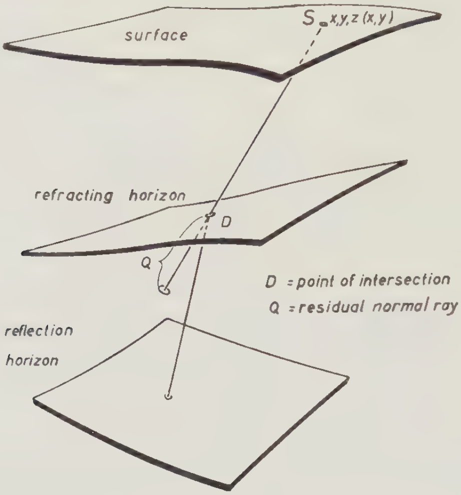

Fig. 3. Illustrating the two layer case

An extension of the method to any sectionally continuous velocity of the individual sequence of layers is in preparation.

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QUELQUES CONSIDERATIONS SUR LES MESURES DE VITESSE EFFECTUEES DANS LES PUITS PAR L'AGIP MINERARIA EN ITALIE ET SPECIALEMENT DANS LA PLAINE DU PO *)

PAR

F. QUARTA et C. MAINO **)

ABSTRACT

The numerous well velocity measurements carried out in Italy by *Agip Mineraria* are considered, in an attempt to establish some correlations between the determined velocities and the stratigraphical and lithological characteristics of the formations in which the measurements were made.

The distribution of the seismic velocity is discussed especially in relation to depth, age and lithologic composition of the Tertiary formations in the Po Valley.

Finally, mention is made of some satisfactory results newly obtained on the basis of such considerations, particularly for the delineation of stratigraphic traps.

Plus on emploie la méthode sismique pour résoudre des problèmes stratigraphiques, plus on est convaincu qu'il est important d'effectuer des contrôles de vitesse le plus exacts possible afin d'obtenir une meilleure corrélation entre les données géologiques et les résultats des prospections sismiques.

On sait que des anomalies de vitesse, ou bien l'application de lois inexactes, peuvent cacher la présence de pièges aussi bien structuraux que stratigraphiques et modifier sensiblement les résultats des observations sismiques.

C'est donc un problème important que celui de mettre en évidence et de déterminer les effets de la nature et de la distribution des terrains sur la vitesse sismique.

Le but de ce travail est d'aborder ce problème.

Les mesures de vitesse sismique effectuées par la Section Géophysique de l'*Agip Mineraria* en Italie, et particulièrement dans la Plaine du Po, dans de nombreux forages, nous permettent de tirer quelques conclusions sur les rapports qui lient la distribution des vitesses aux caractères stratigraphiques et lithologiques des terrains interessés par ces mesures.

Pour établir des corrélations valables entre la vitesse sismique et les caractéristiques géologiques des couches, on a toujours eu soin d'effectuer les mesures dans les forages à des intervalles réguliers, en général en ne dépassant pas les 200 mètres, et toujours au niveau des passages lithologiques et des zones présentant un intérêt dans les carottages électriques; les résultats obtenus peuvent ainsi être rapportés à des intervalles qui ont des caractéristiques géologiques et minéralogiques bien définies.

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*) Presented at the Eleventh Meeting of the European Association of Exploration Geophysicists, held in Milan, 12-14 December 1956.

**) *Agip Mineraria*, Milano.

Dans la Plaine du Pô, où notre travail a été particulièrement intense, on a eu soin de répartir les mesures de vitesse de manière à pouvoir contrôler systématiquement la validité des lois adoptées dans les diverses zones et d'obtenir le plus grand nombre de données possible dans toute la plaine.

Les résultats que nous rapportons ici concernent presque exclusivement une cinquantaine de mesures effectuées dans la Plaine du Po selon une distribution qui est illustrée dans la planche (fig. 1). En général, ces mesures ont été entreprises, sauf quelques exceptions, dans les couches qui appartiennent au Quaternaire, au Pliocène et au Miocène; les caractéristiques principales de celles-ci peuvent être résumées de la façon suivante:

a) Les couches quaternaires sont formées, en grand partie, par des sédiments plus ou moins grossiers, avec intercalations argileuses et argilo-sableuses; souvent la base du Quaternaire (Calabrien) présente un facies généralement argileux.

b) Le Pliocène est caractérisé tant par des formations argilo-marneuses que par des sédiments sableux et des graviers. En général, dans le Pliocène moyen et supérieur prédominent les sables et les argiles, tandis que le Pliocène inférieur présente des marnes, des sables et des graviers qui témoignent de la transgression à la base du Pliocène; presque toujours cette formation transgressive est surmontée d'une couverture argilo-marneuse.

c) Les terrains du Miocène présentent, enfin, des formations sableuses, parfois plus ou moins cimentées, et des couches argilo-marneuses.

Il n'a pas été possible de tenir compte des corrélations entre les données de vitesse et les formations plus anciennes que celles du Miocène à cause du petit nombre de mesures effectuées dans ces terrains.

La sélection des données calculées et considérées dans les graphiques, a été faite selon une méthode semblable à celles employées par Weatherby et Faust (1935), Haskell (1941), Faust (1951), Mühlen et Tuchel (1953), etc. On a, en effet, considéré la moyenne des vitesses relatives à des formations du même âge situées aux mêmes profondeurs. Les intervalles ont été choisis presque toujours de même grandeur; les profondeurs données sur le graphique indiquent leurs profondeurs moyennes à partir du plan de référence, passant généralement par la base des forages de tir. Les temps de parcours introduits dans le calcul de la vitesse ont été toujours ramenés à la verticale.

Pour la classification des formations argileuses et marneuses on a suivi la subdivision de Pettijohn.

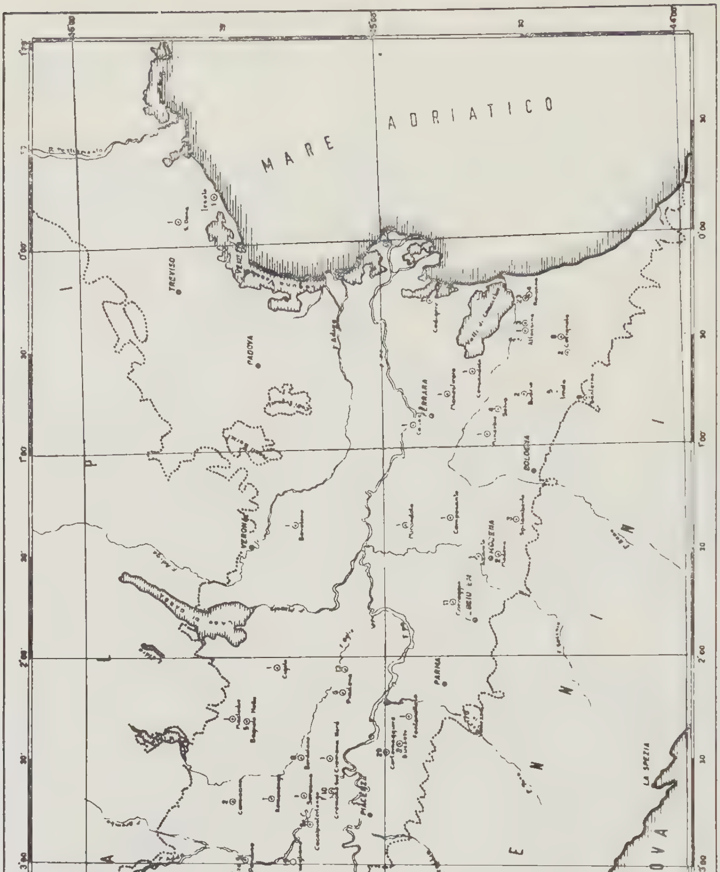

Fig. 1. Distribution des mesures de vitesse dans la Plaine du Po
Distribution of well velocity surveys in the Po Valley

Le graphique de la figure 2 représente la variation de la vitesse d'intervalle dans les formations du Quaternaire suivant les variations de leur profondeur. Il n'a pas été possible de diviser le Quaternaire en zones lithologiques parce que le caractère prédominant des sédiments de cette ère est donné par des variations latérales de facies; la courbe représente donc le comportement de la vitesse d'intervalle dans les formations sablo-argileuses et dans les graviers.

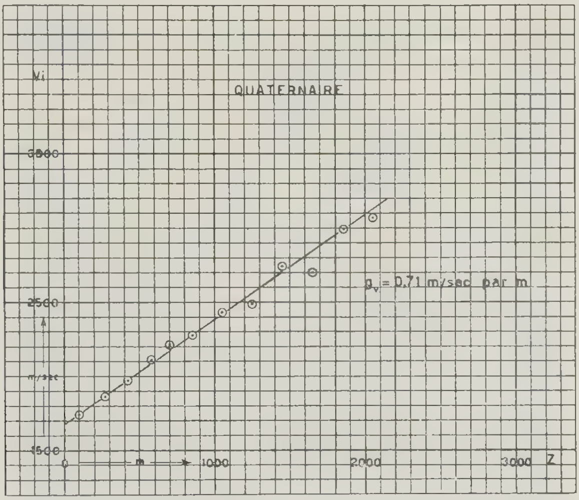

Fig. 2. Variation de la vitesse d'intervalle dans les formations quaternaires.
Variation of interval velocity in quaternary formations

Le gradient vertical mesuré est égal à 0,71 m/sec par mètre de profondeur et la vitesse initiale se trouve être de l'ordre de celle rencontrée dans la plus grande partie de la Plaine du Po.

Le gradient obtenu, en considérant seulement des valeurs de vitesse rapportées à des intervalles presque à la même profondeur, sans pouvoir différencier la lithologie des couches intéressées, se ressent dans ce cas non seulement de l'effet de la surcharge des terrains mais aussi de l'effet des variations lithologiques; toutefois, en ce qui concerne la distribution des vitesses, on a pu constater que la constitution lithologique variable des formations considérées n'a influencé que légèrement l'accroissement presque régulier des valeurs. Les irrégularités à de plus grandes profondeurs peuvent être attribuées à plusieurs causes, comme à d'éventuelles imprécisions d'observation, ou de sensibles variations lithologiques locales dans les intervalles considérés du petit nombre de puits qui ont rencontré le Quaternaire à des profondeurs notables.

Dans la colonne lithologique des terrains du Pliocène et du Miocène il a été possible, au contraire, de faire une distinction entre les formations argileuses et les formations marneuses. On a ainsi pu présenter séparément les résultats obtenus pour chaque formation lithologique et estimer l'accroissement de la vitesse du à la surcharge seule, indépendemment des variations appréciables de la lithologie.

Sur le graphique de la figure 3 sont répresentées les valeurs des vitesses dans les argiles du Pliocène et du Miocène en comparaison des profondeurs des intervalles considérés. Il faut ici préciser que les données qui concernent les argiles du Miocène ne sont pas nombreuses car la plupart des formations imperméables de cet âge sont marneuses: il a été, toutefois, également possible de constater que bien que l'âge des formations varie, leur gradient de vitesse reste constant et on peut raisonnablement le fixer à 0,62 m/sec par mètre de profondeur. La variation due à l'effet stratigraphique se manifeste par un léger accroissement de la valeur constante V_o pour chaque âge, valeur qui peut être considérée comme la vitesse au plan de référence.

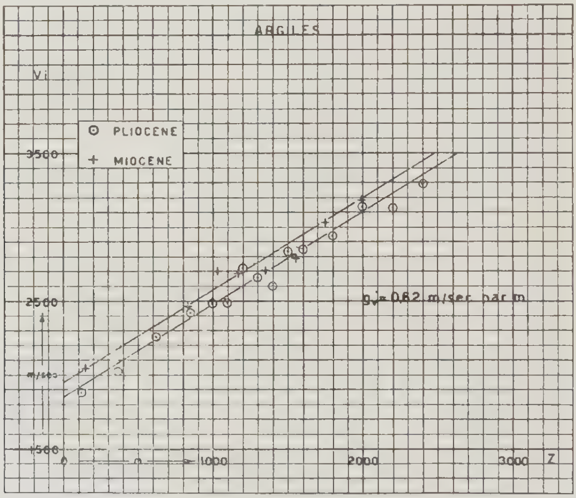

Fig. 3. Variation de la vitesse d'intervalle dans les argiles pliocènes et miocènes.
Variation of interval velocity in pliocene and miocene clays

Pour la variation lithologique des formations interessées l'effet constaté est représenté par une augmentation de la valeur du gradient de vitesse, qui varie de 0,62 m/sec par m. à 0,67 m/sec par m. en passant des argiles aux marnes, (voir figures 3 et 4).

A son tour, la variation due à l'effet stratigraphique dans les mêmes formations marneuses se manifeste par une augmentation encore plus marquée de la valeur initiale V_o que celle constatée dans les formations argileuses.

On peut tirer quelques conclusions importantes des trois graphiques présentés.

Les variations de vitesse considérées dans ces graphiques sont dues en définitive à trois facteurs, ordinairement indiqués comme effet de la surcharge, effet stratigraphique et effet lithologique.

Dans les graphiques des fig. 3 et 4 on a représenté le premier effet puisque il permet une étude comparative plus évidente que les deux autres; pour les formations quaternaires (fig. 2), au contraire, il n'a pas été possible de considérer séparément l'effet de la surcharge parce que dans celles-ci il est impossible d'opérer de nettes différentiations lithologiques.

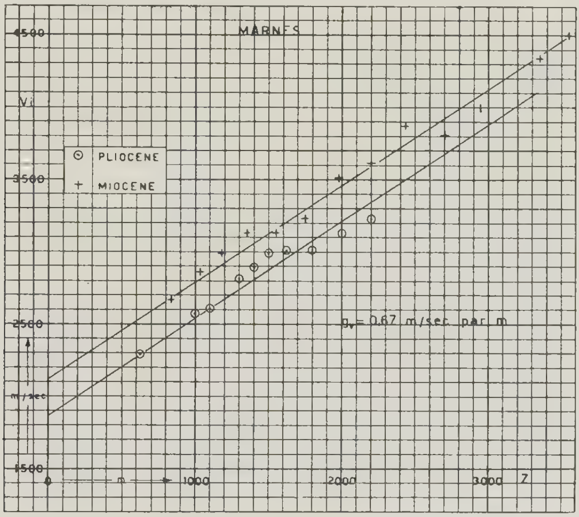

Fig. 4. Variation de la vitesse d'intervalle dans les marnes pliocènes et miocénes
Variation of interval velocity in pliocene and miocene marls

Dans les formations tertiaires considérées, aucune variation appréciable du gradient de vitesse par l'effet de la surcharge ne s'est révélée. Tant pour les argiles que pour les marnes on a pu constater un accroissement tout à fait constant des valeurs des vitesses; c'est pourquoi la représentation linéaire pour les données en examen, est pleinement satisfaisante; toutefois, un plus grand nombre de données aux différentes profondeurs permettront, sans doute, d'établir une courbe représentant mieux le phénomène étudié.

L'effet stratigraphique a manifesté une influence appréciable sur la distribution des vitesses. On a, en effet, pu constater que l'écart, qui lui est dû, entre les valeurs initiales de vitesse, est plus remarquable dans les formations marneuses que dans les formations argileuses considérées; on en déduit que l'effet stratigraphique devient plus grand avec l'accroissement de la densité des formations intéressées.

L'effet lithologique n'a pratiquement qu'une influence limitée pour le genre de formations étudiées; il aurait été bien plus évident s'il eût été possible d'étendre cet examen à des formations ayant une teneur en calcaire plus élévée. La difference de gradient entre formations argileuses et marneuses reste limitée à 0,05 m/sec par m. et ceci peut s'expliquer aussi du fait que la différenciation entre argiles et marnes ne peut pas être toujours établie de façon absolue, étant donné la fréquente présence de termes intermédiaires, c'est à dire d'argiles-marneuses et de marnes-argileuses.

Le graphique se rapportant aux formations du Quaternaire ne concerne pas, comme nous l'avons déjà dit, des unités lithologiques particulières; il met, donc, en évidence les variations des vitesses d'intervalle tant par l'effet de la surcharge que par l'effet lithologique. Le gradient mesuré a été trouvé supérieur à ceux des formations argileuses et marneuses néogènes; on peut trouver une explication de ce fait dans la présence, souvent remarquable, de sables dans les formations examinées. Aussi des études expérimentales effectuées dans nos laboratoires de pétrophysique, ont permis de verifier des accroissements sensibles des valeurs de densité avec l'augmentation des intercalations sableuses dans les formations argileuses et marneuses. Il en résulte que la présence des sables influe sensiblement aussi bien sur l'effet lithologique que sur celui de la surcharge, et particulièrement sur ce dernier si on considère la valeur due à l'effet de la surcharge dans les argiles, c'est à dire dans les formations qui sont lithologiquement les plus proches de la plus grande partie de celles que nous avons considérées dans le Quaternaire.

L'utilisation des résultats des mesures de vitesse sismique en puits et l'application opportune des données déjà exposées, ont permis d'entreprendre un travail systématique de corrélation entre les reliefs sismiques et les données litho-stratigraphiques des champs explorés dans la Plaine du Po; ceci, afin de pouvoir définir plusieurs problèmes stratigraphiques qui se posent dans des zones importantes au point de vue minéralogique.

Le procédé normalement suivi pour ces corrélations, décrit ici brièvement, part de la considération de la lithologie et des carottages électriques de chaque puits du champ étudié et des champs voisins. L'examen est étendu aux mesures de vitesse effectuées dans la zone pour pouvoir confronter les distributions effectives des vitesses et les lois théoriques employées pour les reliefs; de cette façon on peut effectuer une évaluation de l'erreur de représentation des profondeurs des horizons sismiques dans la zone voisine à chacun des puits où ont été effectuées les mesures de vitesse.

S'il se révèle nécessaire d'étendre l'interprétation à des zones intéressées par des puits où des mesures de vitesse n'ont pas été faites, on procède à l'évaluation des corrections à apporter, en examinant les intervalles lithologiques intéressés par les puits, leur profondeur et la stratigraphie.

Ayant, au contraire, à examiner des zones non intéressées par des puits, mais situées dans des positions intermédiaires entre des puits pourvus des données de vitesse, on effectue une interpolation des résultats des mesures existantes et on établit aussi des valeurs proportionnelles des corrections à apporter.

L'application des corrections est ordinairement limitée aux horizons qui ont une plus grande importance pour les buts de recherche; cela afin de réduire la somme du travail de révision des coupes sismiques.

Par le procédé décrit on a la possibilité de corréler les horizons et d'attribuer les ,,phanthoms'' sismiques à des formations du champ ayant un caractère lithologique et stratigraphique bien défini et d'arriver à la détermination finale de situations stratigraphiques particulières non évidentes dans la première phase de la recherche sismique.

L'application pratique de ce que nous avons exposé auparavant à été fait par l'*Agip Mineraria* dans les champs de gaz de Ravenna et Selva-Minerbio.

Par une rigoureuse corrélation des mésures de vitesse effectuées dans les puits, dans ces deux champs, et par la comparaison entre la coupe de vitesse en puits et les carottages électriques, il à été possible de mettre en evidence les niveaux lithologiques différents.

De cette façon on a pu vérifier les possibilités de production des ces deux champs et délimiter avec précision les limites des horizons s'enchâssant à ,,pinch-out'' dans le noyau structural du Pliocène moyen-inférieur, qui représente le motif anticlinal des deux champs.

Ces résultats importants et d'autres obtenus par les corrélations des mesures de vitesse, des reliefs sismiques et des données géologiques, ont rendu évidentes les remarquables possibilités de cette méthode pour mettre en valeur les données obtenues par les moyens normaux de recherche, surtout dans des zones d'interprétation géophysique et géologique difficile. C'est pourquoi nous avons récemment intensifié le regroupement et l'étude de données utiles pour ces correlations, parce que beaucoup de problèmes de recherche sont à envisager dans les zones partiellement explorées ou non encore explorées de la Plaine du Po, de l'Italie centro-méridionale et de la Sicile, où d'importants travaux sont en cours ou prévus.

Les Auteurs adressent leurs remerciements au Dr. T. Rocco pour son assistence et à l'*Agip Mineraria* pour la permission de publier les résultats présentés dans ce travail.

Discussion

K. H. Seelis: Es hat den Eindrück, dass die Geschwindigkeitszunahmen mit der Tiefe, die Sie in Ihrer Darstellungen zeigten, nicht linear sind sondern zur Tiefe hin geringer werden, wie dies auch sonst häufig gemessen ist.

F. Quarta: Das ist wahr aber, in Hinblick auf die untersuchten geologischen Formationen, kann die Darstellung der beobachten Daten nach linearen Gesetzen als recht befriedigendes Ergebnis angesehen werden.

A. Grepin: Quelle methode a été employée pour determiner les zones de biseaux.

F. Quarta: On a consideré les données lithologiques et les carottages électriques de tous les puits de chaque champ etudié: après avoir effectué des mesures de vitesse on a élaboré de nouveau le relief sismique de la zone, en arrivant aussi à attribuer les horizonts et les ,,phanthoms'' sismiques a des formations litho-stratigraphiques bien déterminées, rencontrées dans les puits du champ examiné et des champs voisins.

A l'aide de l'abondant relief sismique et de la considerable quantité de données des puits mis en correlation par ce relief, il a été possible aussi de parvenir à des déterminations très précises de la situation de pièges stratigraphiques qui n'étaient pas facilement relevables séparément par le relief sismique seulement ou bien par les seules données des puits.

A. Farando: What was the influence of the casing on the measurements made. Has the influence of transmission by the cable been noticed?

F. Quarta: Most well velocity measurements were carried out in uncased holes; the average results were duly corrected in case of wells with casing. The influence of energy transmission by cable was also considered, when required. Most measurements were taken, however, using a rubber cable which didn't cause us any of the troubles met with while using a steel cable. In this case due account was taken of them in evaluating the experimental data.

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DIRECT RECORDING VS. FM RECORDING IN SEISMIC TAPE MACHINES *)

BY

LOUIS W. ERATH **)

Abstract

This paper describes the two methods of magnetic tape recording used today in the seismic industry. It discusses objectively the characteristics of both methods including historical material, discussion of circuitry, magnetic tape, drive systems, effects of flutter and harmonic distortion, signal transfer and tape transport construction. The paper also includes discussion of noise and reproduction of transient signals. Diagrams illustrating the two recording systems, their frequency response and phase shift characteristics, distortion and noise levels as well as typical wave forms, are also attached.

There are two methods of magnetic tape recording employed today in the seismic industry. It is the purpose of this paper to discuss the characteristics of these so that one may decide which will be most suitable for given requirements. The first method is Frequency Modulation and the second is that of Bias or Direct Recording. Both have been found suitable for seismic use and the characteristics of each will be compared in this paper.

Early magnetic recording tape was of poor quality. This resulted in the amplitude of a reproduced signal deviating an appreciable amount from the amplitude of a recorded signal. Since FM does not depend on the amplitude of a recorded signal but rather on frequency and frequency deviation it was adopted for use in tape recording of data. FM can be applied with excellent results since it does not depend on the exact amplitude of a playback signal but responds only to its frequency. Tape systems can thus be designed to give good reproduction even though a poor quality of magnetic recording tape is used. Perhaps the earliest use of FM recording was by telemetering people who were interested in obtaining accurately reproducible records of missile data. FM techniques were perfected during World War II and some commercial recorders were put on the market immediately after the war.

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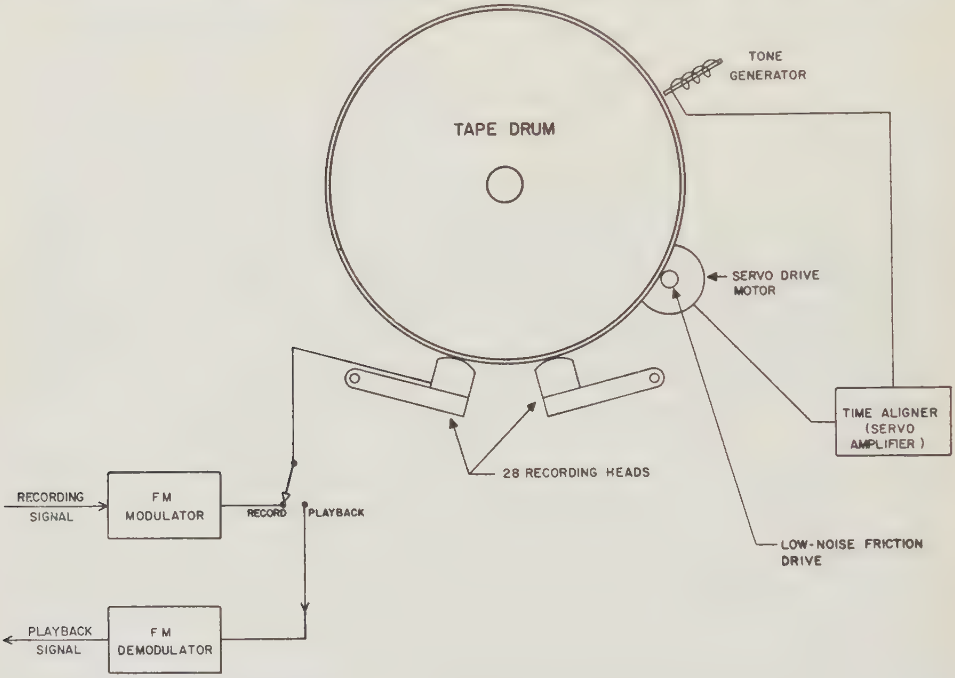
*) Presented at the Eleventh Meeting of the European Association of Exploration Geophysicists, held in Milan, 12-14 December 1956.

**) South Western Industrial Electronics Co. Houston U.S.A.

During World War II Bias or Direct Recording techniques were also developed. Multi-channel direct recorders were used for recording sound produced by submarines. A number of detection microphones were set out and as many as 40 or 50 channels were often used. A direct recorder could be employed since presence of sound was the primary consideration. Noise produced by a submarine could easily be distinguished from random noises and there was little interest in values of instantaneous amplitudes. Bias or Direct recording is also used in magnetic tape recorders designed for home or broadcast studio sound reproduction.



FREQUENCY MODULATION RECORDING SYSTEM

Fig. 1

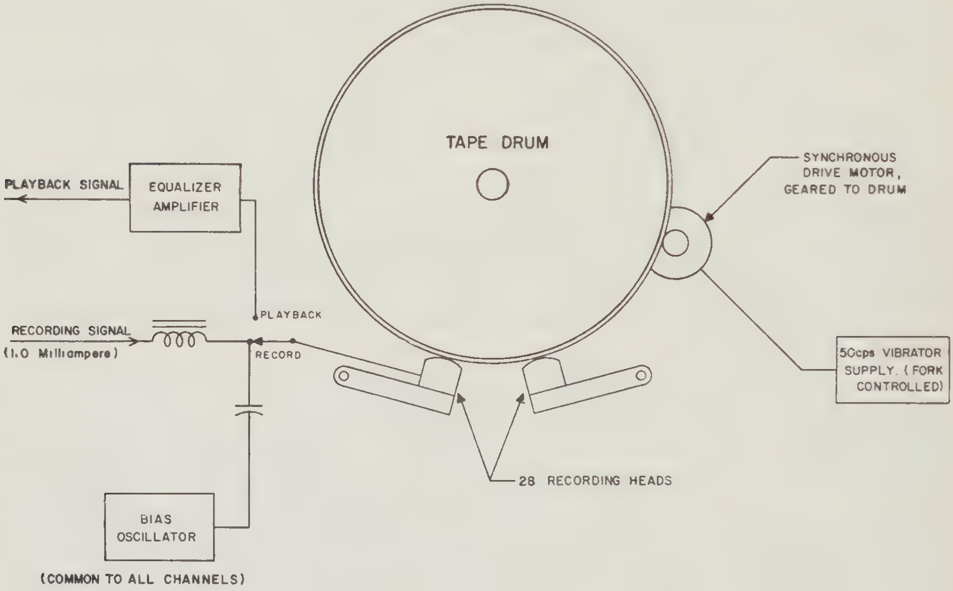
The first attempt to obtain electronically reproducible seismic records employed sound-on-film methods. The processing of film was a difficult, lengthy operation so another method of recording was looked for. Both Direct and FM were adapted for this purpose and the experience gained in technique during World War II made it possible to build successful multi-channel magnetic tape recorders. These proved to be ideally suited to the seismic industry since they were relatively simple and did not require Recording Engineers to operate them as did disc type recorders.

In the FM recording system, (See Fig. 1) modulation is accomplished by feeding the incoming signal to a vacuum tube circuit (FM Modulator) containing an oscillator. The frequency of this oscillator is a function of the amplitude of the input signal and it is operated at some mean value of carrier frequency. As the incoming signal swings positive the carrier frequency is made to increase. As the signal swings negative the value of the carrier decreases. In SIE recording equipment this carrier is 4 KC and the limits of swing or modulation are from 1 KC to 7 KC. The recording tape travels at a linear velocity of 7 ½ ″/sec. The tape on which it is desired to record this high frequency must have a band width capable of accepting this frequency range. If the modulating frequency becomes very high a portion of the incoming energy will be distributed outside the modulation limits. In effect, the energy is distributed into a band width which is broader than the actual deviation. At the highest modulation frequency encountered in seismic applications there is only 1% of signal energy distributed outside of the deviation band. About 99 % of the energy is present within the 1 KC to 7 KC limits. The band width is adequate for recording seismic frequencies up to 300 cps at 100 % modulation and up to 500 cps at reduced values of modulation.

In reproduction or playback of a recorded signal it is desired to reproduce these frequencies and to eliminate the effects of amplitude variations. This demodulation is accomplished by feeding the signal picked up from a head through an amplifier which employs limiters to clip the signals. These clipped signals are fed to a frequency sensitive circuit or discriminator which reconstructs voltages from frequency values. As the frequency deviates the voltage deviates proportionally and the original modulating signal is reproduced. The output of the FM Demodulator contains pulses at carrier frequency with a low frequency or DC component. The carrier must be filtered to allow this low frequency signal to appear in its original form.

In Bias or Direct Recording (See Fig. 2) the incoming signal is superimposed on a high frequency bias and fed to a recording head. The value of the flux imposed on the magnetic tape is proportional to the value of the recording head current. The frequency of the recorded signal is the same as that of the recording head current. The bias is much higher than the highest frequency to be recorded and is obtained by having a bias oscillator associated with the system. This oscillator may be common to all channels provided networks can be arranged to avoid cross coupling between channels at low frequencies. This can be done if the bias frequency is made large with respect to the low frequency. In seismic recording it is generally made 100 times as high as the highest frequency to be used in the seismic spectrum.

In playback the most commonly used head has a coil wound with wire which generates a voltage proportional to the rate of change of the flux rather than the absolute value of the flux. A reproduced signal will thus tend to increase in amplitude as the frequency is increased. This occurs because the peak value of the flux in the tape is constant and therefore the rate of change of the flux is greater at higher frequencies. The rate of change of the flux will increase with the frequency at a rate of 6 db per octave. Each time the frequency doubles the output doubles. The phase of the reproduced signal is also shifted 90° from the phase of the recorded signal by this differentiating action.

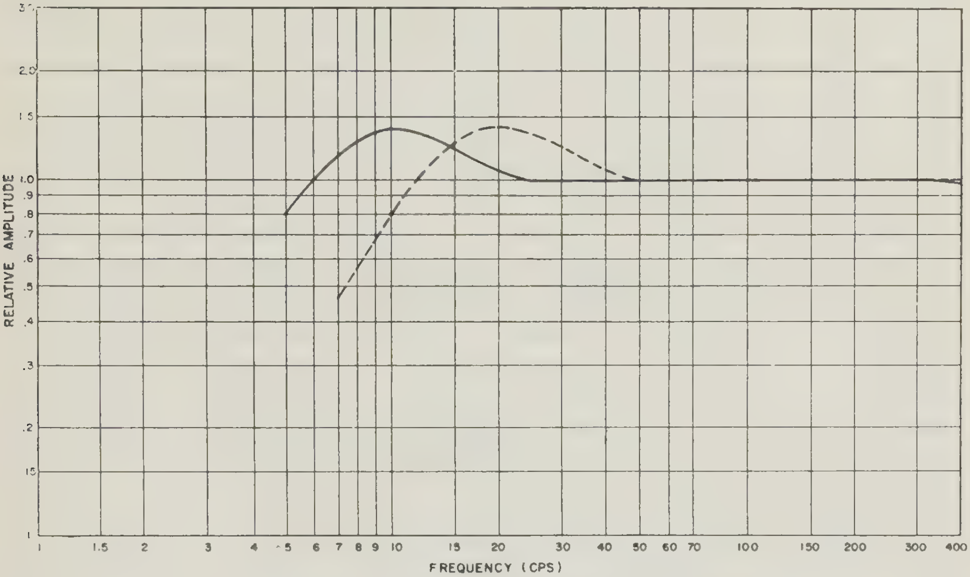


DIRECT OR BIAS RECORDING SYSTEM

Fig. 2

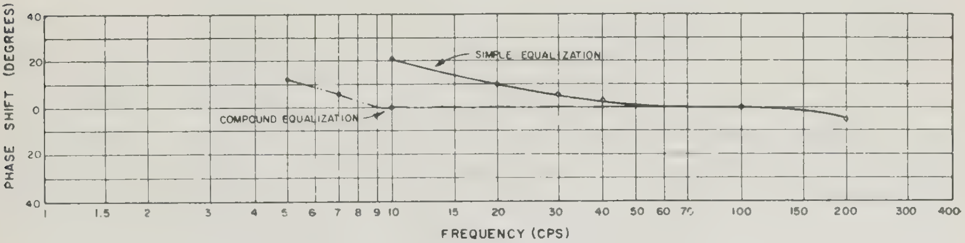
To reproduce a signal the playback amplifier must therefore be properly equalized (See Figures 3 and 4). The equalizer supplies an attenuation as the frequency increases at the rate of 6 db per octave and creates a compensating phase shift of 90°. It is essentially a capacitor bridged to ground in one stage of gain. For this kind of simple equalization the recording system is normally capable of reproducing the original signal shifted about 10° at 20 cps. Equalized amplifiers with compound compensation having zero phase shift down to 10 cps can be constructed. However, they are generally noisier than the type mentioned above.

One of the most talked about quantities in recording is the signal to noise ratio. This is defined as the ratio of some maximum signal to that of noise in the absence of signal. In Direct Recording, since the distortion increases slowly as the amplitude is increased, a value of distortion is chosen to represent maximum recording level. The value of distortion most frequently chosen is between 2 $\frac{1}{2}$ and 3 %. The signal to noise ratio then becomes the ratio of that signal at 3 % distortion to the noise in the absence of signal. Measured using the above definition, the signal to noise ratio for Direct Recording is approximately 60 db in the seismic band from 20 to 200 cps. This means that the signal is 1000 times greater than the reproduced noise. This noise is usually not from the tape itself but from amplifier circuitry. A more interesting figure for noise in Direct Recording is modulation noise or the noise behind the signal which reflects the magnetic uniformity of the recording material. This type of noise is illustrated in Figure 8 in the Playback Envelope for maximum recording level at 300 cps. Note the irregularities in this playback envelope which show this modulation noise and how increased head pressure tends to minimize this noise.



FREQUENCY RESPONSE CURVES (DIRECT RECORDING)

Fig. 3



PHASE SHIFT CURVES (DIRECT RECORDING)

Fig. 4

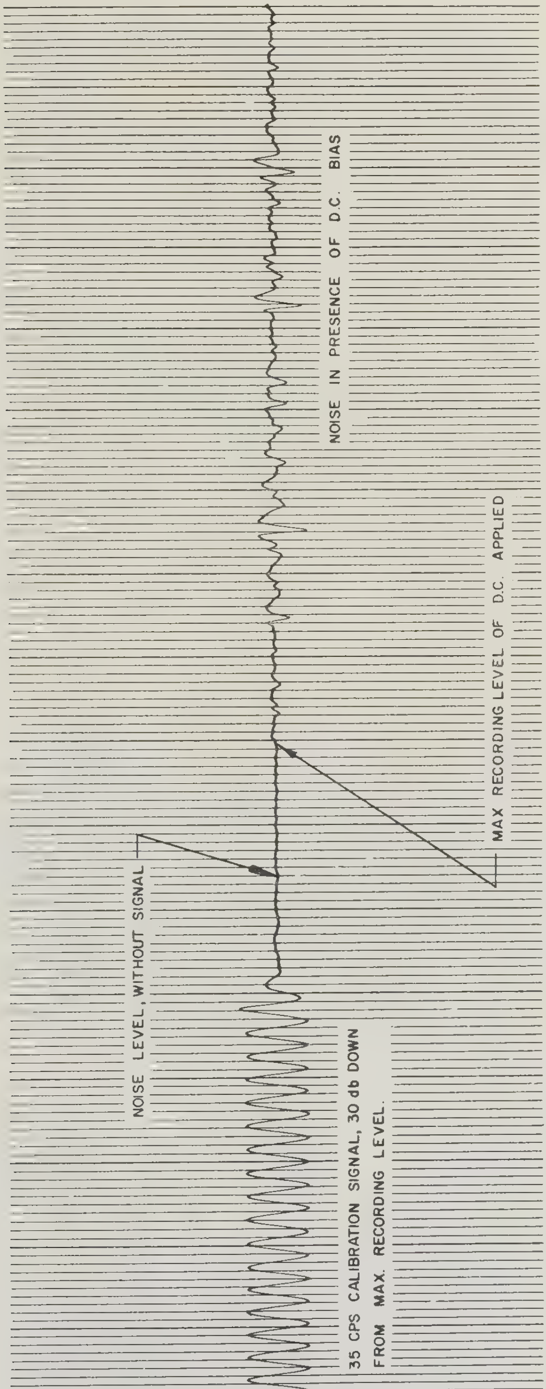
One method of measuring this type of noise is to pass DC through the recording head at a value equal to the peak value of AC at maximum recording level. This places a DC bias on the tape which when played back causes non-uniformity in tape characteristics to generate a flux in the head producing a voltage output appearing as noise. The signal-to-noise ratio on direct recorders when measured in this fashion is a function of the quality of tape used and this noise figure compared to the value of maximum recording level is about 30 to 40 db (See Fig. 5). It should be noted that if a signal has not been recorded on tape, no playback will be obtained regardless of the linear velocity of the tape past the heads.

Another property for comparison between FM and Direct Recording is the reproduction of transients. This problem arises from the fact that the magnetization of the recording media bridges the recording head air gap, and the leading pole face of the head, in effect senses the approach of a quantity of flux. The Time Burst (see Fig. 6) illustrates how the FM system will give a true reproduction while the Direct system exhibits some leader effect on the record. In Direct Recording, with poor head design, this often becomes so severe that in record interpretation computers have been known to choose the leader rather than the true first return or time break.

The most popular arrangement for transporting tape is a drum. Since the maximum length of a seismic record is about 6 seconds, a relatively short piece of tape can be used even though in FM recording the linear velocity of the tape must be at least $7\frac{1}{2}''$ per second. The use of a drum facilitates accurate timing which is the most important single parameter in seismic recording. Transporting the tape on a metal drum that is dimensionally stable provides a stable platform for the recording tape. This allows it to be driven past the heads uniformly with no slipping. Mounting recording tape on a drum also facilitates absolute time control and is generally superior for seismic purposes to continuous belt or reel methods.

Seismic work places stringent timing requirements on tape transport drive systems regardless of the type of recording. The transport could contain short term vibrations or flutter which would not affect average timing severely. In Direct Recording these vibrations would not introduce noise if there was no recorded signal, but when a signal is present variations in tape transport speed would manifest themselves as variations in the amplitude of the reproduced signal. The amount of noise generated is a function of the value of the signal and decreases to zero as the signal approaches zero. Thus when the level of modulation approaches a small value the noise will be proportionately small. This is only true down to the limits of the inherent noise in the amplifier which is about 60 db below the maximum recorded level of signal.

Short term vibrations or flutter does however produce phase jitter in direct

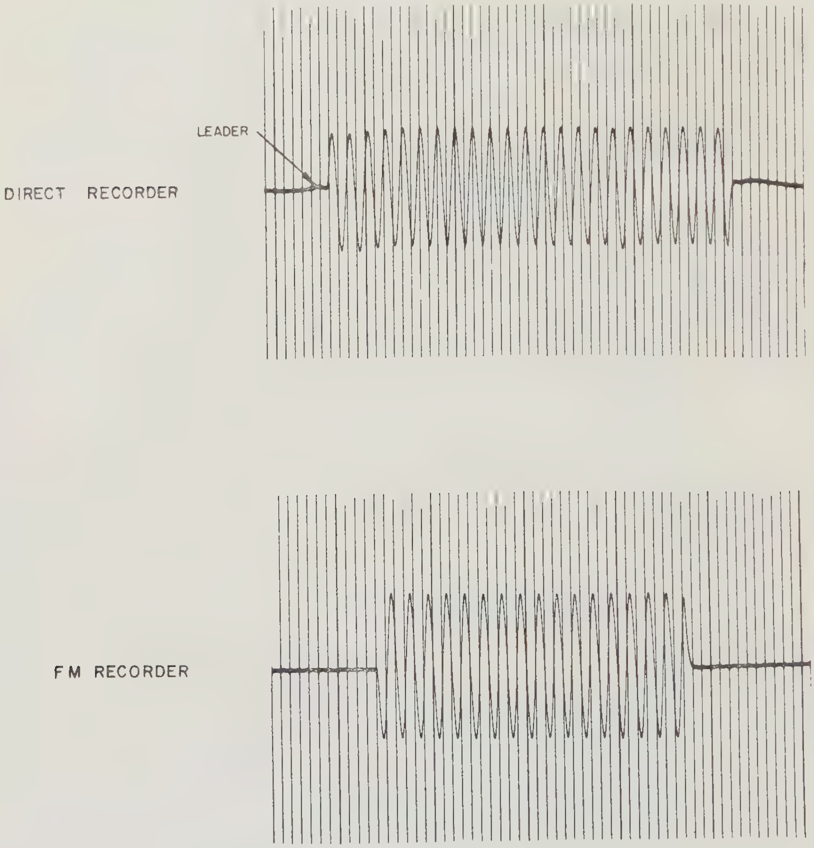


NOISE LEVEL IN A DIRECT RECORDING SYSTEM

Fig. 5

recorders. Tape transport systems which have a timing error of + 1 millisecond due to flutter in the drive mechanism show a ± 45° flutter in the phase of a reproduced 100 cps sine wave.

In FM recording a carrier frequency is present which is being demodulated to produce a voltage. If the drum varies or flutters as it rotates it produces a voltage in the output which appears as noise. As a first approximation the value of this noise is not dependent on the value of modulation. In general the drive mechanism for an FM machine must be quieter than for a direct recorder. Drive mechanisms for FM recorders have been designed which give a signal to noise ratio of about 50 db as measured by the ratio of the maximum signal which can be recorded to the value of noise in the absence of signal. Modulation noise or noise behind the signal in an FM machine is in the order



SIGNAL TEST
Fig. 6

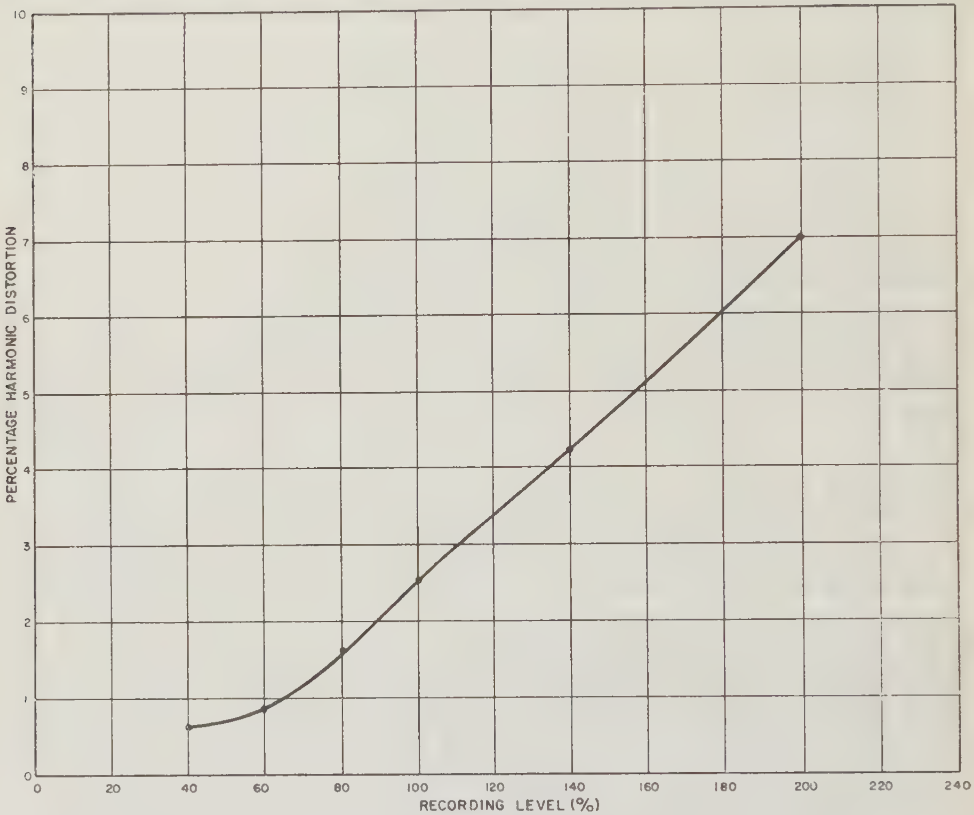
of 60 db below recording level. A noise cancelling circuit is employed with the FM system to cancel mechanical noise in the system. On one channel of the tape machine an unmodulated carrier is recorded reproducing a noise voltage which is the same as is reproduced on all other channels. This noise voltage is then mixed into all channels 180° out of phase and cancels noise in these channels. Signal to noise ratio with noise cancelling is in the order of 60 db. One limitation to the use of noise cancelling is that all noise is not generated by the tape transport. Some noise is caused by tape squirm under the recording heads. This squirm is not uniform from head to head and noise generated in this manner cannot be cancelled. This noise is in a frequency range from about 100 cps to 300 cps which is above the most interesting seismic regions. Its value is about 60 db down from maximum signal.

The use of gears in an FM machine causes vibrations and noise which is translated into electrical noise. For this reason a friction drive is employed in FM systems where drive surfaces are ground to close tolerances. To maintain accurate timing, a tone wheel is mounted on the drum which generates a frequency in a reluctance pickup. The phase of this signal is compared with the phase of a 100 cps tuning fork in a "Time Aligner" circuit. This "Time Aligner" generates a signal which is used to servo control the drive motor. Accuracy over a 6 second range of 1/2 millisecond has been obtained which meets the time requirements for seismic uses. Since the drive current must be continuously variable and frequently at a high rate, the driving energy is obtained from a vacuum tube amplifier. This type power supply is considerably less efficient and larger than the vibrator power supply used with Direct Recording.

In Direct Recording a gear driven tape transport is satisfactory if the drive is of good quality. The drive motor is a synchronous motor driven by a constant frequency derived from a vibrator power supply controlled by a tuning fork. Vibrator power supplies are about 80 % efficient and require less power than do the power supplies used with FM equipment.

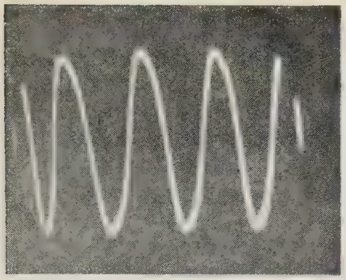
In direct recording the harmonic distortion generated is a function of the amplitude of the recorded signal (See Fig. 7). The greater the recording level the greater the harmonic distortion. The maximum recording level has been chosen at that value which produces 2 ½ to 3 % harmonic distortion. The magnetic tape however may be magnetized to a higher degree. This value may be 2 or 3 times as high as that value which produces 3 % distortion. The only effect of this excessive magnetization is that the distortion increases (See Figure 8).

Seismic signals are of a transient nature with amplitudes varying severely. If a greater than expected amplitude is received it is not clipped but rather produces a higher level of distortion. One of the objectionable features of Direct Recording is that the magnetic material on the tape varies from point to point in its magnetic properties and when played back this causes a variation in the playback envelope. Each cycle has a tendency to be slightly different in size. Another difficulty which is sometimes objectionable is encountered when recording low frequencies. As the magnetic wave length on the tape approaches the dimensions of the head, certain irregularities appear in the response curve (See Figure 3). The response curve would fall off at low frequencies even if a magnetometer type head sensitive to the absolute value of the flux rather than to the rate of change of the flux were used. This is because at DC no external field is produced since the tape is magnetized longitudinally and no poles exist. Variations in the magnetic properties of the tape oxide material and the inherent irregularities of the response curve mean that Direct Recording is not capable of great accuracy in the reproduction of amplitudes. This is not a serious drawback in seismic recording because the reproduction of exact amplitudes is not of prime importance, but if a number of re-recordings

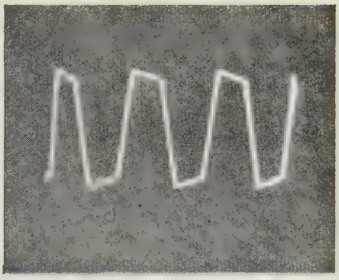


HARMONIC DISTORTION CURVE FOR DIRECT RECORDING SYSTEM TYPE PMR—6

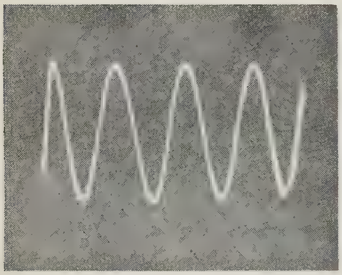
Fig. 7



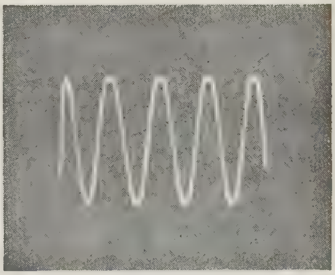
DIRECT RECORDING
200% MODULATION



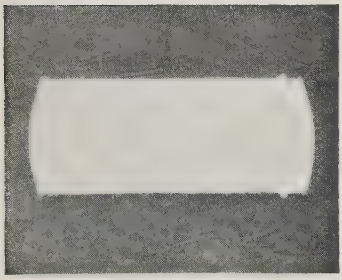
FM RECORDING
200% MODULATION



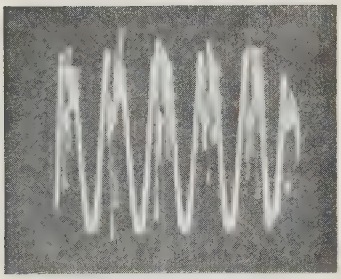
DIRECT RECORDING
100% MODULATION



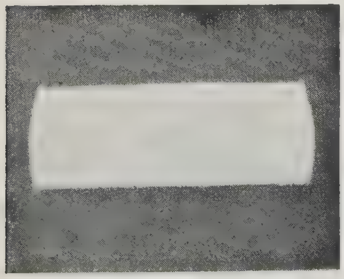
FM RECORDING
110% MODULATION



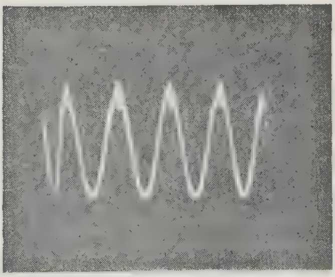
DIRECT RECORDING PLAYBACK ENVELOPE
3 oz. HEAD PRESSURE



FM RECORDING, LIMITER REMOVED
200% MODULATION



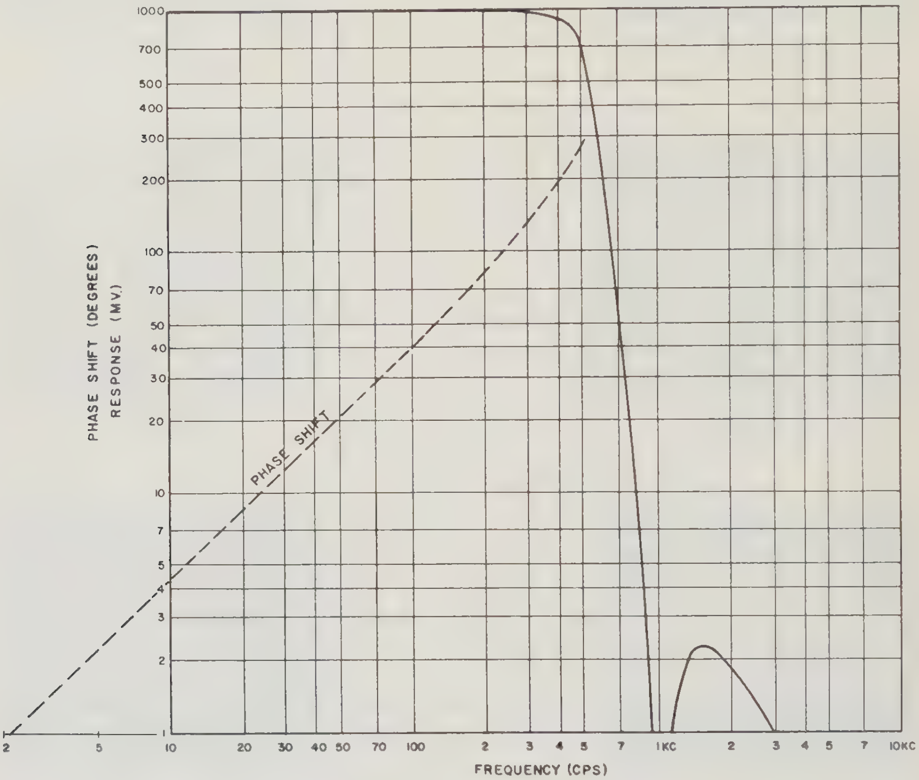
DIRECT RECORDING PLAYBACK ENVELOPE
10 oz. HEAD PRESSURE



FM RECORDING, LIMITER REMOVED
150% MODULATION

TYPES OF SIGNAL
Fig. 8

were necessary for analysis these defects would be multiplied and might become objectionable. The variations in the response curve would be exaggerated with successive re-recordings. The FM system can be made almost ideal from an amplitude standpoint as well as from a time standpoint. The frequency response curve (See Figure 9) illustrates this point. This frequency is limited primarily by the filter which is employed to reject the carrier. The frequency response can be extended down to DC. The filter has a linear phase characteristic and introduces a 1.1 millisecond time error each time the signal is reproduced through the low pass carrier filter.



FREQUENCY RESPONSE AND PHASE SHIFT CURVES (FREQUENCY MODULATION)

Fig. 9

FM signals may be re-recorded in two ways. They may be transferred from tape to tape, FM to FM, without going through the demodulation process. It is desirable to do this when applying time corrections for phenomena such as normal moveout and weathering. The FM signal need only be demodulated when it is desired to display it as a seismic signal, or it is desired to feed it through wave filters. Many people are considering the possibility of using direct recording in the field for its simplicity and light weight and then transcribing to FM for analysis. In such techniques as record stacking (as described in an earlier paper *) it is sometimes necessary to re-record the signal as many as 20 times. An FM system would be desirable in this case.

TABLE

Electrical Characteristics	*FM Recording*	*Direct Recording*
Signal/Noise Ratio	60 db	60 db
Modulation Noise	60 db	40 db
Instantaneous Amplitude Reproduction	Excellent, Better than 1/10 %	Fair + 5 % using top quality recording tape
Cross Talk	-60 db	-50 db
Frequency Response	Smooth ± 1/2 db, 0 to 300 cps	3 db bump at 10 cps
Phase Response	Linear phase shift 0 to 300 cps	Zero phase shift 20 to 300 cps
Harmonic Distortion at Maximum Recording Level	1/2 %	2 1/2 % to 3 %
Ability to handle Over-Modulation	Poor (Signal degenerates to noise)	Good Harmonic distortion increases to about 7 % at about twice normal recording level
Ability to transcribe successively	Excellent	Fair
Tape Transport Considerations	*Fm Recording*	*Direct Recording*
Tape Speed	7.5 ″/sec.	3.75 ″/sec.
Drive Mechanism	Friction	May be gear driven
Timing Control	Tuning fork and servo control	Tuning fork and synchronous motor
Effects of drive flutter	Introduces phase jitter, noise and timing errors	Introduces phase jitter and timing errors
Drive system power requirements	250 Watts	120 Watts
Associated Electronic Equipment		
Field Use		
Recording	Requires Modulators	May be driven directly from seismic amplifiers or from a one tube recording amplifier. Requires one tube bias oscillator common to all channels.
Monitoring Playback	Requires Demodulators	May be played back into input of seismic amplifiers without additional electronic circuitry.
Office Use		
Recording and playback	Requires Modulators and Demodulators	Requires equalized playback amplifiers

*) *"A Compositing Technique for Improving the Quality of Seismic Records"* By Louis W. Erath, Southwestern Industrial Electronics Company, P. O. Box 13058, Houston 19, Texas.

Recording Tape Considerations		
Quality	Average quality may be used	Best available quality should be used
Demagnetizing before use	Not required	Careful demagnetizing must be done
Susceptibility to magnetic damage after recording	Not great	Considerable care must be exercised to keep tapes from magnetic fields.
	FM Recording	*Direct Recording*
Susceptibility to Physical Damage	Scratches in oxide or sand collected on tape will produce a sharp transient in playbank	Small scratches in oxide only produce slight effect on recorded signal. Sand and dust on tape have little effect on playback.

One defect of an FM system occurs when it is over modulated. The carrier is swung down into the pass band or swung so high that it does not play back. One method of preventing the carrier from being broken down into noise is to include a limiter to prevent over modulation. The effects of this limiter are illustrated in Figure 8. In FM recording the amount of crossfeed between channels can be made negligible and 60 db is not uncommon. In direct recorders crossfeed is a limitation which is in the order of 50 db at 20 cps. It tends to decrease as the frequency is raised however, since the wave length on the tape is made shorter.

In FM the demodulator can be designed so that the amount of harmonic distortion generated is almost negligible. It is usually in the order of ½% and less at lower frequencies. This is important for even if the FM signal were demodulated and remodulated it could be re-recorded many times without serious deterioration. FM allows a playback record to be made which is identical with the original record. In most cases the reproduced record cannot be distinguished from the original.

The tape transports for Direct Recording cost about the same as those for FM recorders but the associated circuitry needed with an FM system is considerably more expensive. Both FM and Direct Recording systems have been used successfully for seismic recording and developments are now in progress which will greatly improve both systems. Research is being conducted into tape transport mechanisms which will allow greater signal to noise ratio in the future for FM machinery. One of the most serious objections to FM is the elaborate electronic apparatus which must be used with it. Work is being done to simplify the systems so that they will be more portable. In Direct Recording, magnetic tape manufacturers are carrying out development work and tapes of superior quality are being tested which will reduce some of the causes of amplitude deficiencies. It should be remembered that the correct system to be used for specific applications must depend on individual requirements.

PRINZIPIELLE BEMERKUNGEN ZU THEORIE UND PRAXIS DER METHODE DER ZWEITEN ABLEITUNG BEI DER INTERPRETATION GRAVIMETRISCHER MESSERGEBNISSE

VON

OTTO ROSENBACH *)

Abstract

The first part of the paper deals with theoretical considerations concerning the arithmetic mean of gravity values and its use with regard to the derivation of approximation formulae for the second derivative. In order to calculate the second derivative in practice the arithmetic mean $\bar{g}(r)$ of a continuum of gravity values on a circle of radius r is approximated by a Taylor polynomial and then replaced by the arithmetic mean $\dot{g}_n(r)$ of n discrete gravity values. Because of the invariance of $\bar{g}(r)$ with regard to rotations of the coordinate system in the horizontal datum plane there exists a lower limit for the number n; this lower limit depends on the degree of the Taylor polynomial used in the formula for g_{zz}.

The general results of the first part yield routine formulae for the special case of a regular hexagonal grid; these formulae are given and discussed in the second part of the paper. Three formulae are applied to the gravity data of the Los Angeles Basin. Some remarks concerning the comparability of different approximation formulae and some hints with regard to routine calculations conclude the paper.

Zusammenfassung:

Im ersten Teil der Arbeit werden einige theoretische Überlegungen in bezug auf die Verwendung des arithmetischen Mittels von Schwerewerten zur Herleitung von Näherungsformeln für die zweite Ableitung angestellt. Für die praktische Berechnung der zweiten Ableitung g_{zz} wird das arithmetische Mittel $\bar{g}(r)$ eines Kontinuums von Schwerewerten auf einem Kreis vom Radius r um den Aufpunkt durch ein Taylor-Polynom approximiert und dem arithmetischen Mittel $\dot{g}_n(r)$ von n diskreten Schwerewerten gleichgesetzt. Auf Grund der Invarianz von $\bar{g}(r)$ gegenüber Drehungen des Koordinatensystems in der horizontalen Bezugsebene ergibt sich für die Zahl n eine Limitierung nach unten, und zwar in Abhängigkeit von der Ordnung des Taylor-Polynoms, das die Grundlage zur Herleitung einer Formel für g_{zz} bildet.

Die allgemeinen Formeln des ersten Teils liefern durch Spezialisierung die Gebrauchsformeln für ein regelmässiges Sechseckgitter, die im zweiten Teil

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angegeben und diskutiert werden. Es erfolgt eine Anwendung von drei Formeln auf das Messgebiet des Los Angeles Basin. Überlegungen hinsichtlich der Vergleichbarkeit verschiedener Näherungsformeln für die zweite Ableitung und einige Hinweise zur routinemässigen Bearbeitung praktischer Messergebnisse bilden den Abschluss der Arbeit.

INHALT

1. Einleitung.
2. Die Verwendung des arithmetischen Mittels zur Herleitung von Näherungsformeln für die 2. Ableitung.
   2.1 Das Taylor-Polynom für $\bar{g}(r)$.
   2.2 Approximation von $\bar{g}(r)$ durch $\dot{g}_n(r)$.
   2.3 Die Minimalzahl der Summanden von $\dot{g}_n(r)$.
   2.4 Näherungsformeln für die 2. Ableitung.
3. Die Anwendung von Näherungsformeln für die 2. Ableitung bei der Bearbeitung praktischer Messergebnisse.
   3.1 Gebrauchsformeln für ein regelmässiges Sechseck-Gitter.
   3.2 Ein Beispiel: Das Los Angeles Basin.
   3.3 Über die Vergleichbarkeit verschiedener Näherungsformeln für die 2. Ableitung.
   3.4 Einige Hinweise zur routinemässigen Bearbeitung praktischer Messergebnisse.

1. *Einleitung*

Die Berechnung der 2. Ableitung der Störschwere nach der Vertikalrichtung bildet heute vielfach ein Standardverfahren bei der Auswertung gravimetrischer Messergebnisse. Es sind mehrere, ihrer Konzeption nach unterschiedliche Methoden für die Herleitung von Formeln zur Berechnung der 2. Ableitung aus den Bouguer-Anomalien publiziert worden. In jedem Falle handelt es sich um *Näherungs*formeln, die je nach Wahl der auftretenden Parameter für die Interpretation verschieden brauchbar sind.

Bei einigen Methoden gründet sich die Herleitung von Formeln für die 2. Ableitung auf die Darstellung des Anomalienfeldes in der Nachbarschaft des Aufpunktes durch ein Taylor-Polynom. In bezug auf diese Methoden sollen im folgenden einige prinzipielle Gesichtspunkte diskutiert werden, deren Bedeutung für die anderen gebräuchlichen Methoden durch sinngemässe Übertragung der entsprechenden Fragestellungen geprüft werden könnte.

2. *Die Verwendung des arithmetischen Mittels zur Herleitung von Näherungsformeln für die 2. Ableitung.*

2.1 Das Taylor-Polynom für das arithmetische Mittel $\bar{g}(r)$.

Bezeichnet $g\ (x, y, 0)$ die Bouguer-Anomalie in der horizontalen Bezugsebene von Fig. 1, dann ist das arithmetische Mittel $\bar{g}\ (r)$ der Funktion g auf einem Kreis vom Radius r um den Punkt P, mit Verwendung von $x = r \cos \varphi$, $y = r \sin \varphi$, gegeben durch

$$g(r) = \frac{1}{2\pi} \int_0^{2\pi} g(r \cos \varphi,\ r \sin \varphi,\ o)\, d\varphi. \tag{1}$$

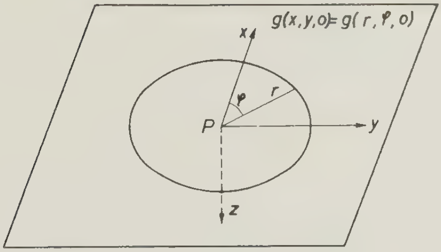

Fig. 1: Horizontale Bezugsebene für die Bouguer-Anomalien g und Koordinatenbezeichnung
Horizontal datum plane for the Bouguer anomaly g and notation of coordinates

Das arithmetische Mittel ist eine Funktion von r, die durch ein Taylor-Polynom

$$\bar{g}(r) \approx g^{\mathrm{P}} + a_2 r^2 + a_4 r^4 + \ldots + a_{2\mathrm{M}}\, r^{2\mathrm{M}}, \tag{2}$$

mit

$$a_{2\mu} = \frac{1}{(2\mu)!} \left(\frac{d^{2\mu}\, \bar{g}(r)}{dr^{2\mu}} \right)^{P},\ \mu = 1, 2, \ldots, M \tag{2a}$$

approximiert werden kann; die Koeffizienten der ungeraden Potenzen von r verschwinden.

Der Koeffizient des quadratischen Gliedes in (2) ist

$$a_2 = -\frac{1}{4} g_{zz}^{P}, \tag{3}$$

wobei g_{zz}^{P} die 2. Ableitung der Bouguer-Anomalie nach der Vertikalrichtung bedeutet, die im folgenden kurz als „2. Ableitung" bezeichnet wird. — Eine Herleitung von (3) findet sich z.B. bei Elkins (1951); in Abweichung hiervon ist der Ausdruck (3) auch sehr leicht herzuleiten, indem man den Differentialquotienten in (2a) für $\mu = 1$ durch zweimalige Differentiation von (1) unter dem Integralzeichen berechnet und berücksichtigt, dass die Bouguer-Anomalie der Differentialgleichung von Laplace genügt.

Das Polynom (2) dient nun zur Berechnung der gesuchten 2. Ableitung g_{zz}^{P} aus dem Anomalienfeld g. Entnimmt man diesem für eine Anzahl k verschiedener Radien r_j, $j = 1, 2, \ldots, k$, die zugehörigen arithmetischen Mittel $\bar{g}(r_j)$, so entstehen k lineare Gleichungen, aus denen die Unbekannte g_{zz}^{P} zu errechnen ist. Das Gleichungssystem ist lösbar, wenn k hinreichend gross ist, wofür sowohl der Grad des Näherungspolynoms als auch weitere Gesichtspunkte massgebend sind, auf die in Abschnitt 2.4 eingegangen wird. — Hier soll vorerst die Technik der Entnahme von $g(r)$ aus dem Anomalienfeld g in der Praxis einer Betrachtung unterzogen werden.[1])

2.2 Approximation von $\bar{g}(r)$ durch $\dot{g}_n(r)$.

In der Praxis wird das Anomalienfeld g aus Gravimetermessungen an diskreten, genügend eng gewählten Stationen erhalten, indem die Linien gleicher Anomalie, die sogen. Isogammen möglichst genau gezeichnet werden. Die Bestimmung des Wertes $g\,(r)$ erfolgt nun nicht durch tatsächliche Ausführung der Integration gemäss (1), sondern vermittels einer Approximation des Integrals durch eine Summe, und zwar gewöhnlich in folgender Weise: Man teile den Vollwinkel um P in n gleiche Teile $\Delta\varphi_i = 2\pi/n$; sodann wähle man auf dem zu $\Delta\varphi_i$ gehörigen Bogenstück des Kreises mit dem Radius r einen beliebigen Punkt $Q_i\,(r, \varphi_i)$, in dem also die Anomalie den Wert $g\,(r, \varphi_i)$ annimmt. Bei einer derartigen Einteilung wird auf Grund der Definition des bestimmten Integrals der Ausdruck (1) für $\bar{g}\,(r)$ approximiert durch die Summe

$$g\,(r) \approx \frac{1}{2\pi} \sum_{i=1}^{n} g\,(r, \varphi_i)\,\Delta\,\varphi_i = \frac{1}{n} \sum_{i=1}^{n} g\,(r, \varphi_i) = \dot{g}_n\,(r). \tag{4}$$

Es ist also das arithmetische Mittel $\dot{g}_n\,(r)$ der n Anomalienwerte $g\,(r, \varphi_i)$ an den diskreten Punkten $Q_i\,(r, \varphi_i)$ eine Approximation für $\bar{g}\,(r)$. Über die Lage der Punkte Q_i auf den Kreisbögen der Länge $\frac{2\pi r}{n}$ ist mit (4) noch nicht verfügt. Normalerweise wird man die Q_i so legen, dass sie den Kreis in n gleiche Bogenstücke einteilen; jedoch wird gelegentlich in der Praxis hiervon abgewichen.

Die Approximation (4) ist gültig für jedes $n \geqq 1$, wenn auch selbstverständlich mit unterschiedlicher Güte. Im folgenden Abschnitt soll geklärt werden, inwieweit n zusätzlichen Bedingungen unterliegt, wenn $\dot{g}_n\,(r)$ anstatt $g\,(r)$ bei der Berechnung der 2. Ableitung g_{zz}^P benutzt wird.

2.3 Die Minimalzahl der Summanden von $\dot{g}_n(r)$.

Wie bereits am Schluss von Abschnitt 2.1 kurz ausgeführt wurde, dient das Polynom (2) zur Berechnung der 2. Ableitung aus dem Anomalienfeld. Die zu verschiedenen Radien r_j gehörenden Darstellungen der $\bar{g}\,(r_j)$ ergeben ein lineares Gleichungssystem zur Bestimmung von g_{zz}^P; hierbei werden für die numerische Rechnung die $g\,(r_j)$ nach (4) durch $\dot{g}_n\,(r_j)$ ersetzt. Ist nun die Zahl n der Summanden in $\dot{g}_n\,(r_j)$ beliebig wählbar? Für die vorliegende Aufgabe der Errechnung von g_{zz}^P ergibt die nachstehende Überlegung, dass n eine gewisse

---

[1]) Diejenigen Leser, die mehr praktisch orientiert sind, können ohne wesentliche Beeinträchtigung des Verständnisses die beiden folgenden Abschnitte überschlagen und mit ihrer Lektüre sofort bei Abschn. 2.4 oder evtl. sogar 3.1 fortfahren.

Minimalzahl übersteigen muss, wenn die Ersetzung von $g(r_j)$ durch $\dot{g}_n(r_j)$ sinnvoll sein soll.

Das arithmetische Mittel $\bar{g}(r)$ des Kontinuums der Anomalienwerte $g(r, \varphi)$ ist auf Grund seiner Definition (1) unabhängig von der Orientierung des xy-Koordinatensystems in der horizontalen Bezugsebene von Fig. 1. Diese Unabhängigkeit gilt daher ebenfalls für die Koeffizienten in (2), insbesondere also für g^P_{zz}, was sich mit Hilfe der Laplaceschen Gleichung auch sofort direkt aus der Invarianz von $g^P_{xx} + g^P_{yy}$ gegenüber Drehungen des Koordinatensystems ergibt.

Das Näherungspolynom (2) wird bei der praktischen Rechnung nicht $\bar{g}(r)$, sondern $\dot{g}_n(r)$ gleichgesetzt. Nun lässt sich aber auch $\dot{g}_n(r)$ durch ein Näherungspolynom der Ordnung 2M darstellen, indem man in (4) die Werte $g(r, \varphi_i)$ von P aus nach Taylor bis zur Ordnung 2M entwickelt und die entstehenden n Polynome addiert. Soeben wurde konstatiert, dass die Koeffizienten des Polynoms (2) unabhängig sind von der Orientierung des xy-Koordinatensystems; diese Tatsache lässt folgende Forderung als sinnvoll erscheinen:

> Die Ersetzung von $\bar{g}(r)$ darf nur durch solche $\dot{g}_n(r)$ erfolgen, in deren jeweiligem Näherungspolynom der Ordnung 2M ebenfalls nur Glieder gerader Ordnung auftreten mit Koeffizienten, die sämtlich invariant gegenüber Drehungen des xy-Koordinatensystems in der Bezugsebene sind.

Eine Auskunft darüber, welche $\dot{g}_n(r)$ in diesem Sinne zur Ersetzung von $\bar{g}(r)$ geeignet sind, gibt Tab. 1. Man gelangt zu ihr in folgender Weise:

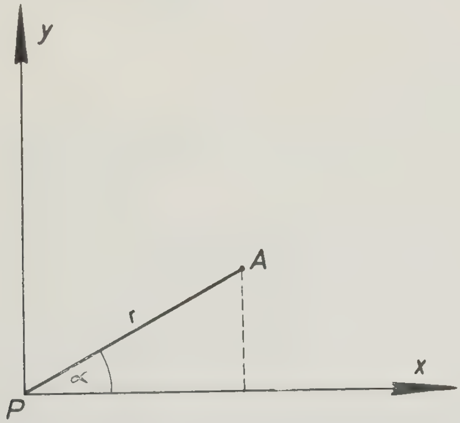

Fig. 2: Geometrische Bezeichnungen zu Formel (5)
Geometrical notations concerning formula (5)

Nach Fig. 2 lautet bei Verwendung von Polarkoordinaten r, α das Taylor-Polynom für die Schwereanomalie g^A im Punkte A von P aus:

$$g^A = g\,(r, \alpha) = \sum_{m=0}^{2M} \frac{r^m}{m!} \left[\sum_{l=0}^{m} \binom{m}{l} \left(\frac{\partial^m g}{\partial x^{m-l}\, \partial y^l} \right)^p \cos^{m-l}\alpha \,\sin^l\alpha \right] \tag{5}$$

Mit Hinblick auf Abschn. 2.2 identifiziere man nun den Punkt A mit dem Punkt $Q_1\,(r, \varphi_1)$ einer Anordnung von n Punkten $Q_i\,(r, \varphi_i)$, $i = 1, 2, \ldots, n$, die den Kreis mit dem Radius r in n gleiche Bogenstücke teilen. Dann ergibt sich aus (4) für $\dot{g}_n\,(r)$ die Darstellung

$$\dot{g}_n\,(r) \approx \frac{1}{n} \sum_{i=1}^{n} \left\{ \sum_{m=0}^{2M} \frac{r^m}{m!} \left[\sum_{l=0}^{m} \binom{m}{l} \left(\frac{\partial^m g}{\partial x^{m-l}\, \partial y^l} \right)^P \cos^{m-l}\left(\alpha + \frac{2\pi\,(i-1)}{n}\right) \sin^l\left(\alpha + \frac{2\pi\,(i-1)}{n}\right) \right] \right\}. \tag{6}$$

In dieser Darstellung dürfen nun gemäss der oben formulierten Forderung an die Eigenschaften von $\dot{g}_n\,(r)$ nur Glieder gerader Ordnung auftreten, deren Koeffizienten invariant gegenüber Drehungen des xy-Koordinatensystems, d.h. unabhängig von α sein müssen. Das führt nach Umformung von (6) in den Ausdruck

$$\dot{g}_n\,(r) \approx \frac{1}{n} \sum_{m=0}^{2M} \frac{r^m}{m!} \left\{ \sum_{l=0}^{m} \binom{m}{l} \left(\frac{\partial^m g}{\partial x^{m-l}\, \partial y^l} \right)^P \left[\sum_{i=1}^{n} \cos^{m-l}\left(\alpha + \frac{2\pi\,(i-1)}{n}\right) \sin^l\left(\alpha + \frac{2\pi\,(i-1)}{n}\right) \right] \right\}. \tag{7}$$

zu der Forderung:

$$\sum_{i=1}^{n} \cos^{m-l}\left(\alpha + \frac{2\pi\,(i-1)}{n}\right) \sin^l\left(\alpha + \frac{2\pi\,(i-1)}{n}\right) = \begin{cases} 0 \text{ für } m = 2\mu - 1 \\ \text{unabhängig von } \alpha \text{ für } m = 2\,\mu \end{cases} \tag{8}$$

$$\mu = 0, 1, 2, \ldots, M;\ m \geqq l.$$

Diese Forderung ist keineswegs für alle Kombinationen der Zahlen m, l, n erfüllt. — Eine allgemeine Behandlung der Summe in (8) ist hier nicht von Interesse. Min Hinblick auf die Bedürfnisse der Praxis ist in Tab. 1 der Wert dieser Summe für $m = 1, 2, \ldots, 6$ und $n = 2, 3, 4, 6, 8$ angegeben. Eine Erweiterung der Tabelle auf höhere m sowie andere n ist leicht möglich.

Wie Tab. 1 zeigt, wird die Forderung (8) bei $M = 1$ erfüllt für $n = 3, 4, 6, 8$, jedoch nicht für $n = 2$; entsprechend bei $M = 2$ erfüllt für $n = 6, 8$, aber nicht für $n = 2, 3, 4$. Das bedeutet nach den zu Anfang dieses Abschnittes angestellten Überlegungen: Soll die Darstellung (2) von $\bar{g}\,(r)$ bis zum Glied 2. (oder 4.) Ordnung gehen und $\dot{g}_n\,(r)$ gleichgesetzt werden, so muss $n \geqq 4$ (oder

Tab. 1: Wert der Summe in (8) für m = 1, 2, . . . 6 und n = 2, 3, 4, 6, 8.

m	l	n = 2	n = 3	n = 4	n = 6	n = 8	n* = 8
1	0	0	0	0	0	0	0
	1	0	0	0	0	0	0
2	0	$2\cos^2\alpha$	$\frac{3}{2}$	2	3	4	4
	1	$\sin 2\alpha$	0	0	0	0	0
	2	$2\sin^2\alpha$	$\frac{3}{2}$	2	3	4	4
3	0	0	$\frac{3}{4}(1-4\sin^2\alpha)\cos\alpha$	0	0	0	0
	1	0	$-\frac{3}{4}(1-4\cos^2\alpha)\sin\alpha$	0	0	0	0
	2	0	$-\frac{3}{4}(1-4\sin^2\alpha)\cos\alpha$	0	0	0	0
	3	0	$\frac{3}{4}(1-4\cos^2\alpha)\sin\alpha$	0	0	0	0
4	0	$2\cos^4\alpha$	$\frac{9}{8}$	$2(\cos^4\alpha+\sin^4\alpha)$	$\frac{9}{4}$	3	$4(\cos^4\alpha+\sin^4\alpha)$
	1	$\sin 2\alpha\cos^2\alpha$	0	$\frac{1}{2}\sin 4\alpha$	0	0	0
	2	$\frac{1}{2}\sin^2 2\alpha$	$\frac{3}{8}$	$\sin^2 2\alpha$	$\frac{3}{4}$	1	$2\sin^2 2\alpha$
	3	$\sin 2\alpha\sin^2\alpha$	0	$-\frac{1}{2}\sin 4\alpha$	0	0	0
	4	$2\sin^4\alpha$	$\frac{9}{8}$	$2(\cos^4\alpha+\sin^4\alpha)$	$\frac{9}{4}$	3	$4(\cos^4\alpha+\sin^4\alpha)$
5	0	0	abhängig von α	0	0	0	0
	1	0		0	0	0	0
	2	0		0	0	0	0
	3	0		0	0	0	0
	4	0		0	0	0	0
	5	0		0	0	0	0
6	0	abhängig von α	abhängig von α	abhängig von α	abhängig von α	$\frac{5}{2}$	$4(\cos^6\alpha+\sin^6\alpha)$
	1					0	0
	2					$\frac{1}{2}$	$\sin^2 2\alpha$
	3					0	0
	4					$\frac{1}{2}$	$\sin^2 2\alpha$
	5					0	0
	6					$\frac{5}{2}$	$4(\cos^6\alpha+\sin^6\alpha)$

$\geqq$ 6) sein, damit die entsprechende Näherung (7) von 2. (oder 4.) Ordnung hierfür geeignet ist; bei der soeben angegebenen Limitierung von n ist nicht nur die Forderung (8) erfüllt, überdies verschwindet in der Taylor-Entwicklung von $\dot{g}_n(r)$ das auf die jeweilige Näherung (7) folgende Glied 3. (oder 5.) Ordnung.

Unter Bezugnahme auf die Darlegungen am Schluss von Abschnitt 2.1 und am Anfang dieses Abschnittes ergibt sich somit für die Praxis folgende Tatsache: Verwendet man zur Berechnung von g_{zz}^P Näherungspolynome vom Grade 2M = 4 für die $g(r_j)$, die durch $\dot{g}_n(r_j)$ ersetzt werden sollen, so ist es zweckmässig, $n \geqq 6$ zu wählen; dann sind die Koeffizienten der erhaltenen Näherungsformel für g_{zz}^P unabhängig von der Orientierung des xy-Koordinatensystems in der horizontalen Bezugsebene (Fig. 1). Eine solche Unabhängigkeit ist jedoch nicht mehr vorhanden, falls man $n = 4$ wählt, wenn also z.B. ein quadratisches Punktgitter der Berechnung zugrundegelegt wird (Rosenbach, 1953). – In diesem Zusammenhang werde noch eine Bemerkung angefügt, die Missverständnissen vorbeugen soll: Es sei eine praktische Berechnung von g_{zz}^P aus dem Anomalienfeld mit einer Näherungsformel durchgeführt, deren Koeffizienten invariant sind gegenüber Drehungen des xy-Systems. Trotzdem ist das Ergebnis im allgemeinen abhängig von (starren) Drehungen der n-Tupel von Punkten Q_i auf den Kreisen mit den Radien r_j. Diese Abhängigkeit ist jedoch nicht durch die Koeffizienten der Formel bedingt, sondern alleine dadurch, dass die Werte $\dot{g}_n$ (r_j) von derartigen Drehungen abhängig sind, was bei den Taylor-Entwicklungen der $\dot{g}_n$ (r_j) in den Gliedern höherer Ordnung als 2M zum Ausdruck kommt (vgl. z.B. Tab. 1). — Hiernach lässt sich nunmehr auch eine frühere Untersuchung (Rosenbach, 1954, S. 134/135) über den Einfluss der Orientierung eines quadratischen Punktgitters auf das Ergebnis einer Berechnung von g_{zz}^P in folgender Weise beurteilen: Die in Fig. 6 der zitierten Arbeit veranschaulichte Abhängigkeit der 2. Ableitung nach Rosenbach von der Orientierung des Punktgitters ist bedingt durch die entsprechende Abhängigkeit sowohl der Formelkoeffizienten als auch der Summen von g-Werten.

Bei Benutzung eines quadratischen Punktgitters der Maschenweite s ist es normalerweise üblich, auch die 8 Punkte zu verwenden, die auf dem Kreis mit dem Radius $s\sqrt{5}$ liegen, ihn aber nicht in gleiche Bogenstücke teilen (vergl. z.B. Rosenbach, 1954, Fig. 2). Auf diese Anordnung von Punkten bezieht sich in Tab. 1 die letzte Spalte $n^* = 8$, die sich sofort aus der Addition zweier Spalten $n = 4$ für die Winkel α und $\alpha' = \frac{\pi}{2} - \alpha$ ergibt. Wie die Spalte $n^* = 8$ zeigt, sind die Terme 4. Ordnung nicht invariant gegenüber Drehungen des xy-Systems, obwohl die Zahl der Punkte die gleiche ist wie bei $n = 8$.

2.4 Näherungsformeln für die 2. Ableitung.

Nunmehr wenden wir uns der Herleitung von Näherungsformeln zur Berechnung von g_{zz}^P in der Praxis zu. Wie bereits am Schluss von Abschnitt 2.1 zum Ausdruck gebracht, dient hierzu das Polynom (2) für k verschiedene Radien r_j:

$$g(r_j) \approx g^P - \frac{1}{4} g_{zz}^P \, r_j^2 + a_4 \, r_j^4 + \ldots + a_{2M} \, r_j^{2M}, \quad j = 1, 2, \ldots, k. \tag{9}$$

In diesem System von k Gleichungen sind die linken Seiten als bekannt anzusehen, die später durch geeignete $\dot{g}_n$ (r_j) zu ersetzen sind. Auf den rechten Seiten sind die Potenzen der r_j bekannt, da die Radien ja willkürlich wählbar sind; hingegen sind die Koeffizienten dieser Potenzen Unbekannte, so auch die gesuchte 2. Ableitung g_{zz}^P. Die hier noch auftretende Grösse g^P kann als bekannt oder unbekannt angesehen werden; im ersten Falle sind auf der rechten

Seite des Systems (9) M, im zweiten Falle $M + 1$ Unbekannte vorhanden. Entsprechend muss für die Lösbarkeit des Systems $k = M$ bzw. $M + 1$ sein; dann ist das System auch stets lösbar, da die Nennerdeterminante jeweils eine Vandermondesche Determinante ist. Ist in den beiden genannten Fällen $k > M$ bzw. $> M + 1$, so liegt eine Überbestimmung vor und zur Lösung des Systems wird gewöhnlich die Ausgleichungsrechnung benutzt; hierauf wird an späterer Stelle in diesem Abschnitt noch eingegangen werden.

Nachstehend sind die Lösungen des Systems (9) bei bekanntem sowie unbekanntem g^P für $M = 1{,}2$ angegeben:

Fall 1: g^P bekannt.

a) $M = 1 = k$:

$$g_{zz}^P \approx \frac{4}{r_1^2} \{ g^P - \bar{g}(r_1) \} \tag{10}$$

b) $M = 2 = k$:

$$g_{zz}^P \approx \frac{4}{r_1^2 r_2^2 (r_2^2 - r_1^2)} \{ (r_2^4 - r_1^4) g^P - r_2^4 g(r_1) + r_1^4 g(r_2) \} \tag{11}$$

Fall 2: g^P unbekannt.

a) $M = 1 = k\text{-}1$:

$$g_{zz}^P \approx \frac{4}{r_2^2 - r_1^2} \{ g(r_1) - g(r_2) \} \tag{12}$$

b) $M = 2 = k\text{-}1$:

$$g_{zz}^P \approx \frac{4}{(r^2_3 - r_2^2)(r_3^2 - r_1^2)(r_2^2 - r_1^2)} \{(r_3^4 - r_2^4)\bar{g}(r_1) - (r_3^4 - r_1^4)\bar{g}(r_2) + \\ + (r_2^4 - r_1^4)\bar{g}(r_3)\} \tag{13}$$

Wie bereits ausgeführt, werden bei einer praktischen Berechnung die $\bar{g}(r_j)$ der obigen Formeln nach (4) durch geeignete

$$\dot{g}_{n_j}(r_j) = \frac{1}{n_j} \sum_{i=1}^{n_j} g(r_j, \varphi_i) \tag{14}$$

ersetzt, wobei

$$\Delta\varphi_i = \varphi_i - \varphi_{i-1} = \frac{2\pi}{n_j}, \ \varphi_0 = \varphi n_j \tag{14a}$$

ist. Geeignet heisst gemäss Abschnitt 2.3, dass n_j genügend gross ist; also z.B. bei $M = 2$ muss $n_j \geqq 6$ sein, während nach Tab. 1 für $n_j = 4$ oder $n_j^* = 8$ das arithmetische Mittel (14) nicht geeignet erscheint. Die Ausgangsrichtung $\varphi_0 = \varphi_{n_j}$ ist bei geeigneten $\dot{g}_{n_j}(r_j)$ beliebig.

In den Formeln (10) — (14) ist über die Radien r_j noch nicht verfügt. Diese müssen in gewissen Grenzen den Forderungen der speziellen Aufgabe angepasst werden; d.h. die Radien r_j müssen so dimensioniert sein, dass die gravimetrische Wirkung der zu erfassenden geologischen Struktur hinreichend die Summen (14) beeinflusst und so vermöge einer der Formeln (10) — (13) in g_{zz}^P erkennbar wird. Allerdings dürfen dabei die Radien weder zu klein noch zu wenig voneinander verschieden sein; denn sind sie zu klein, so werden die Summen in (14) einander praktisch gleich, womit g_{zz}^P nahezu verschwindet, sind sie hingegen zu wenig voneinander verschieden, so werden die Faktoren vor den Parenthesen zu gross, womit Fehler in den einzelnen g-Werten zu stark in g_{zz}^P wieder zum Vorschein kommen. — Diese Bemerkungen über die Dimensionierung der Radien r_j sind nun nicht so zu verstehen, dass hierüber in jedem neuen Messgebiet neu zu entscheiden ist; vielmehr soll damit nur zum Ausdruck gebracht werden, dass es normalerweise zweckmässig ist, grössere bzw. kleinere Radien zu verwenden, um die gravimetrische Wirkung tiefer bzw. höher gelegener Strukturen in g_{zz}^P zu erkennen. — Hiermit werde diese Betrachtung vorerst abgebrochen; es wird darauf in Abschnitt 3.1 nochmals näher eingegangen, und zwar bei der Diskussion von Gebrauchsformeln, die sodann zur Bearbeitung des praktischen Beispiels in Abschnitt 3.2 verwandt werden.

Über die gegenseitige Lage der Punkte $Q\ (r_j,\ \varphi_i)$, an denen die Anomalienwerte $g(r_j,\ \varphi_i)$ für (14) zu entnehmen sind, ist bisher nichts ausgesagt. Insbesondere brauchen diese Punkte keinem regelmässigen Gitternetz anzugehören; andererseits dürfen sie es aber auch ohne weiteres, wenn die damit festgelegten n_j bei vorgegebenem Grad $2M$ der Näherungspolynome für $g\ (r_j)$ die Bedingung (8) erfüllen. Bilden die Punkte $Q\ (r_j,\ \varphi_i)$ kein regelmässiges Gitternetz, so erfordert die Errechnung *eines* Wertes g_{zz}^P die Ablesung von $\sum_{j=1}^{k} n_j$ Anomalienwerten aus dem Isogammenplan; bilden die Punkte $Q\ (r_j,\ \varphi_i)$ hingegen ein regelmässiges Gitternetz, so erfordert die Errechnung *eines* Wertes g_{zz}^P auch nur die Ablesung *eines* Anomalienwertes, wenn man von den zusätzlich benötigten Anomalienwerten in einem gewissen Randstreifen des Messgebietes absieht. Hiermit kann sich für die Praxis ein erheblicher Unterschied im notwendigen Arbeitsaufwand ergeben, je nachdem ein regelmässiges Gitternetz benutzt wird oder nicht. Jedoch darf man den Gesichtspunkt des evtl. erheblich geringeren Aufwandes an Ablesearbeit alleine nicht ausschlaggebend sein lassen für die generelle Benutzung eines regelmässigen Gitternetzes, wie in Abschnitt 3.4 näher erläutert wird.

Die bisherigen Ausführungen beziehen sich auf den Fall, dass das Gleichungssystem (9) eindeutig nach der Cramerschen Regel zu lösen ist. Zu Beginn dieses Abschnittes wurde bereits erwähnt, dass im Falle einer Überbestimmung gewöhnlich die Ausgleichungsrechnung zur Lösung des Systems benutzt wird. So kann das von Elkins in seiner grundlegenden Arbeit über die 2. Ableitung

(Elkins, 1951) entwickelte Verfahren zur Berechnung von g_{zz}^P mit Bezug auf das System (9) in folgender Weise beschrieben werden: Der Punkt P gehöre einem quadratischen Gitternetz der Maschenweite s an. Zur Lösung des Gleichungssystems (9) für $M = 1$ dienen die bekannten Werte $g^P, g_{n_1}(s)$, $g_{n_2}(s\sqrt{2}), g_{n_3}^*(s\sqrt{5})$ mit $n_1 = n_2 = 4$ und $n_3^* = 8$ (vgl. Tab. 1); das System ist somit zweifach überbestimmt. — Überbestimmte Systeme werden bei teilweise modifizierten Zielsetzungen auch z.B. von Linsser (1955a, b) und Brown (1956) mit Hilfe der Ausgleichungsrechnung oder eng verwandter Methoden gelöst.

Die Benutzung überbestimmter Systeme hat vom mathematischen Standpunkt aus folgenden Sinn: Die Berechnung von g_{zz}^P ist eigentlich eine numerische Differentiation, die bekanntlich stark empfindlich in bezug auf Fehler in den Ausgangswerten ist. Daher erscheint eine Glättung der Ausgangswerte vielfach angebracht. Eine solche Glättung wird aber automatisch erreicht, wenn ein überbestimmtes Gleichungssystem durch Ausgleichung gelöst wird.

Es sind aber auch die mit Hilfe einfach bestimmter Gleichungssysteme (9) erhaltenen Näherungsformeln (10) — (13) dazu in der Lage, automatisch in verschiedener Stärke zu glätten, wenn nur die Formelparameter entsprechend geeignet gewählt sind. Hierauf wird in den Abschnitten 3.1 und 3.2 näher eingegangen; die dortigen Ergebnisse zeigen, dass es zwecks Erreichung einer Glättung keineswegs notwendig ist, zur Herleitung von Gebrauchsformeln für die 2. Ableitung überbestimmte Gleichungssysteme zu verwenden.

In der weiteren Untersuchung wird von der Behandlung überbestimmter Systeme Abstand genommen. Hierfür ist nicht nur der soeben behandelte Gesichtspunkt der Glättung massgebend, sondern die beiden nachstehend angegebenen Gründe sprechen ebenfalls dafür. Der erste Grund ist ein praktischer: Man denke sich (9) bei festem M als bestimmtes bzw. überbestimmtes System behandelt, die Anzahl der Radien sei k bzw. k' $(> k)$, ausserdem seien die n_j für $j = 1, 2, \ldots, k$ in beiden Fällen die gleichen; dann enthält die Lösung des Systems k bzw. k' Summen (14), d.h. aber, dass der Arbeitsaufwand bei Anwendung der aus dem überbestimmten System hergeleiteten Formel für g_{zz}^P grösser ist als bei derjenigen aus dem bestimmten System. — Der zweite Grund für eine ausschliessliche Behandlung bestimmter Gleichungssysteme (9) ist theoretischer Natur und liegt ein wenig tiefer: Man denke sich wiederum (9) bei festem M als bestimmtes bzw. überbestimmtes System behandelt, und zwar mit Verwendung von k bzw. k' $(> k)$ Radien; die jeweiligen n_j bzw. $n_{j'}$ seien geeignet gewählt und bleiben für das weitere fest. Wenn man nun in den allgemeinen Ausdrücken für die Lösungen g_{zz}^P bzw. $(g_{zz}^P)'$ die grössten Radien r_k bzw. $r_{k'}$ über alle Grenzen wachsen lässt, während die anderen Radien endlich bleiben, zeigen die Lösungen in den beiden Fällen ein grundsätzlich verschiedenes Verhalten. Die Lösung des bestimmten Systems geht in die entsprechende für $M = M - 1$ und $k = k - 1$ über; hingegen werden in der Lösung des überbestimmten Systems für grosses $r_{k'}$ (und festen anderen Radien) sämtliche Koeffizienten sehr klein, um im Grenzfall $r_{k'} \to \infty$ zu verschwinden. Das bedeutet aber für die Praxis, dass u.U. eine Struktur im Bild der 2. Ableitung nicht erkannt werden kann, weil der Radius des äussersten Kreises zu gross gewählt worden ist. Wie unbefriedigend die Verwendung einer solchen Formel sein kann, zeigt die folgende Überlegung: Es sei in einem praktisch unendlich ausgedehnten, linearen Regionalanstieg der Bouguer-Anomalien deutlich die lokale gravimetrische Wirkung einer Struktur erkennbar. Das Isogammenbild werde mit solchen Formeln g_{zz}^P bzw. $(g_{zz}^P)'$ bearbeitet, für die r_k bzw. $r_{k'}$ so gross seien, dass die Anomalienwerte auf den zugehörigen Kreisen von der Struktur nicht mehr beeinflusst werden; die anderen Radien r_j bzw. $r_{j'}$ mögen in der Grössenordnung des gravimetrischen Wirkungsbereiches der Struktur in der Bezugsebene liegen. Dann arbeitet die Formel g_{zz}^P so, als ob der Kreis mit dem Radius r_k nicht berücksichtigt wird; sie kann also durchaus die Struktur im Bild der 2. Ableitung sichtbar machen. Demgegenüber nützt es bei der Formel $(g_{zz}^P)'$ gar nichts, dass $(k' - 1)$ Kreise im Wirkungsbereich der Struktur liegen, also auch die gravimetrische Wirkung der Struktur in die Formel eingeht; alleine der zu grosse Radius $r_{k'}$ bewirkt praktisch verschwindende Koeffizienten vor den Summen (14), so dass es nicht möglich ist, die Struktur im Bild der 2. Ableitung sichtbar zu machen.

Hiermit möge die weitgehend theoretisch orientierte Betrachtung über die Herleitung von Gebrauchsformeln für die 2. Ableitung beendet sein. In den nachfolgenden Abschnitten wird nunmehr auf die praktische Anwendung solcher Formeln eingegangen.

3. *Die Anwendung von Näherungsformeln für die 2. Ableitung bei der Bearbeitung praktischer Messergebnisse.*

Die im letzten Abschnitt angegebenen Formeln (10) — (13) dürften bei passender Wahl der Radien r_j sowie hinreichend grossen n_j in (14) den Erfordernissen der Praxis weitgehend genügen. Da es sich hierbei lediglich um *Näherungs*formeln handelt, werden verschiedene Formeln mit jeweils verschiedenen oder auch gleichen r_j, n_j bei Anwendung auf das gleiche Anomalienfeld im allgemeinen mehr oder minder verschiedene Approximationen des wahren g_{zz}-Feldes liefern. Es ist daher notwendig, aus der Mannigfaltigkeit der verfügbaren Formeln eine Auswahl für die praktische Anwendung zu treffen. Eine solche Auswahl ist nur möglich auf Grund eines näheren Studiums der „Eigenschaften" spezieller Formeln, das in bezug auf einige wesentliche Gesichtspunkte in den Abschnitten 3.1 — 3.4 durchgeführt wird.

3.1 Gebrauchsformeln für ein regelmässiges Sechseck-Gitter.

Zunächst soll aus Gründen der Zweckmässigkeit der Diskussion ein regelmässiges Sechseck-Gitter nach Fig. 3 zugrunde liegen. Die Kantenlänge s des Gitters wird normalerweise in der Grössenordnung benachbarter Gravimeterstationen zu wählen sein. — Mit Bezugnahme auf die Kreise A, B, C, D und die auf ihnen liegenden Punkte in der Fig. 3 hat eine Näherungsformel für die 2. Ableitung die Gestalt

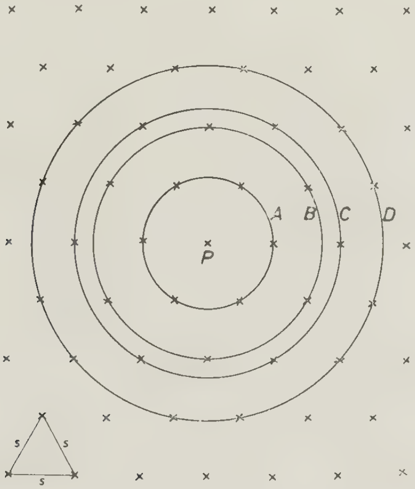

Fig. 3: Sechseck-Gitter der Kantenlänge s. Hexagonal grid of spacing s.

$$g_{zz}^P \approx K \left[f^P g^P + f^A \sum_{i=1}^{6} g_i^A + f^B \sum_{i=1}^{6} g_i^B + f^C \sum_{i=1}^{6} g_i^C + f^D \sum_{i=1}^{12} g_i^D\right] \qquad (15)$$

dabei sind diejenigen Koeffizienten f gleich Null, deren zugehörige Kreise für die Herleitung einer speziellen Formel nicht benutzt worden sind. Tab. 2 gibt nun die Koeffizienten K und f von 12 solcher Formeln an, die sich aus (10) — (13) errechnen, wenn dort (14) mit den jeweiligen geometrischen Daten r, n aus dem unteren Teil der Tabelle eingesetzt wird.

Durch die Benutzung eines regelmässigen Sechseck-Gitters ist sichergestellt, dass die Anzahlen n der Punkte auf den Kreisen A, B, C im Sinne der Bemerkung anschliessend an (14a) genügend gross sind, um in den Reihen für $\bar{g}$ bzw. $\dot{g}$ die Glieder bis $M = 2$ „sinnvoll" zu erfassen. Diese Aussage gilt auch für die 12 Punkte auf dem Kreis D, obwohl diese (14a) nicht erfüllen; denn die „unregelmässige" Anordnung der 12 Punkte auf D entsteht ja durch Superposition von zwei „regelmässigen" Anordnungen mit je 6 Punkten, wie sie auch bei den Kreisen A, B, C vorliegen.

Tab. 2 Koeffizienten K und f einiger Näherungsformeln für g^P_{zz} nach (15) sowie geometrische Daten über die benutzten Punktanordnungen bei Verwendung des regelmässigen Sechseck-Gitters von Fig. 3.

(Die Formeln ergeben die Näherungswerte von g^P_{zz} in 10^{-15} cgs, wenn die Kantenlänge s in km und die Anomalienwerte g in 0,01 mgal gemessen werden).

Berechnet aus:	Formel Nr.	K	f^P	f^A	f^B	f^C	f^D	Mittlerer Fehler der Näherungsformel für g_{zz} (E = mittlerer Fehler der g-Werte)
(10)	I	$2/3s^2$	+ 6	− 1	0	0	0	4,32 E/s^2
	II	$1/6s^2$	+ 6	0	0	− 1	0	1,08 E/s^2
(11)	III	$1/9s^2$	+ 48	− 9	+ 1	0	0	5,88 E/s^2
	IV	$1/18s^2$	+ 90	− 16	0	+ 1	0	5,45 E/s^2
	V	$1/18s^2$	+ 42	0	− 16	+ 9	0	3,42 E/s^2
	VI	$1/126s^2$	+ 198	0	0	− 49	+ 8	1,85 E/s^2
(12)	VII	$1/3s^2$	0	+ 1	− 1	0	0	1,15 E/s^2
	VIII	$2/9s^2$	0	+ 1	0	− 1	0	0,77 E/s^2
	IX	$1/18s^2$	0	+ 2	0	0	− 1	0,30 E/s^2
(13)	X	$1/9s^2$	0	+ 7	− 15	+ 8	0	5,00 E/s^2
	XI	$1/18s^2$	0	+ 10	− 12	0	+ 1	2,13 E/s^2
	XII	$1/54s^2$	0	+ 22	0	− 32	+ 5	1,79 E/s^2
Geometrische Daten:	Kreis		P	A	B	C	D	
	Radius: r		0	s	$\sqrt{3}\,s$	2s	$\sqrt{7}\,s$	
	Anzahl der Punkte: n		1	6	6	6	12	

Wie die Tab. 2 zeigt, nehmen die Koeffizienten in den einzelnen Formeln recht unterschiedliche Werte an. Hieraus folgt eine unterschiedliche Fortpflanzung von Fehlern der Anomalienwerte g in die jeweiligen Näherungswerte g^P_{zz}. Die letzte Spalte der Tabelle gibt den mittleren Fehler (standard deviation) der Näherungswerte von g^P_{zz} an unter der Voraussetzung, dass E = const der mittlere Fehler eines jeden Anomalienwertes g ist; d h. ein Wert in der letzten Tabellenspalte gibt den mittleren Fehler der entsprechenden rechten Seite von (15) auf Grund des Fehlerfortpflanzungsgesetzes an.

Der mittlere Fehler ist nun für die Anwendung der Formeln in zweifacher Hinsicht von Bedeutung:

1) Seiner Natur nach ist der mittlere Fehler ein Mass für die Streuung der *näherungsweise errechneten* Werte g_{zz}, d.h. für die Streuung der rechten Seite einer Näherungsformel (15) für g_{zz}, bedingt durch die Streuung E der g-Werte. — Erfahrungsgemäss besitzen in der praktischen Anwendung Formeln mit kleinerem (grösserem) mittleren Fehler eine Tendenz zu stärkerer (schwächerer) Glättung der Ergebnisse (vgl. hierzu auch Abschn. 2.4). Haben also ober-

flächennahe Dichtestörungen durch unvollkommene Erfassung der Dichte bei der Reduktion der Schwerewerte einen fehlerhaften Einfluss auf die Anomalien, so besteht nur bei Anwendung von Formeln mit kleinerem mittleren Fehler begründete Aussicht, die gravimetrische Wirkung geologischer Strukturen im Bild der 2. Ableitung erkennen zu können.

2) Der mittlere Fehler gestattet bis zu einem gewissen Grade eine Aussage über die ,,Fähigkeit'' einer Formel, die gravimetrische Wirkung verschiedener Bauelemente in der Erdkruste wiederzugeben: Um grossräumige, tiefer gelegene bzw. kleinräumige, höher gelegene Strukturen in den errechneten Näherungswerten von g_{zz} sichtbar machen zu können, empfiehlt sich die Anwendung von Formeln mit kleinerem bzw. grösserem mittleren Fehler. Das ergibt sich sofort bei Betrachtung der Tab. 2. Dort sind innerhalb der 4 Formelgruppen, die sich von (10) — (13) herleiten, die einzelnen Formeln im Sinne abnehmender mittleren Fehler angeordnet. Wie ein Blick auf die geometrischen Daten im unteren Teil der Tabelle lehrt, ist diese Abnahme gleichzeitig verbunden mit einer Vergrösserung der Ausdehnung der jeweiligen Punktkonfiguration, die der betreffenden Formel zugrunde liegt. Andererseits besitzen grossräumige, tiefer gelegene Strukturen einen grösseren Wirkungsbereich in der Bezugsebene als kleinräumige, höher gelegene. Es ist daher durchaus plausibel, dass sich zur Erfassung einer Struktur mit grösserem (kleinerem) Wirkungsbereich solche Formeln empfehlen, deren zugrunde liegende Punktkonfiguration ein grösseres (kleineres) Flächenstück bedecken, deren mittlere Fehler also kleiner (grösser) sind.

Kommt allerdings in einem Messgebiet zur gravimetrischen Wirkung kleinräumiger, höher gelegener Strukturen noch diejenige oberflächennaher Dichtestörungen hinzu, so wird es vielfach schwer oder sogar unmöglich sein, einen Kompromiss zwischen den entsprechenden Forderungen nach 1) und 2) zu finden.

Hiermit werde die Diskussion der Näherungsformeln für g_{zz} vorerst abgebrochen. Sie wird in Abschnitt 3.3 fortgeführt, nachdem im folgenden Abschnitt 3.2 die Ergebnisse der Anwendung einiger Formeln auf ein praktisches Beispiel besprochen worden sind.

3.2 Ein Beispiel: Das Los Angeles Basin.

Für die praktische Anwendung von Näherungsformeln zur Berechnung von g_{zz} erscheint es wünschenswert, dass die benötigten Anomalienwerte ohne Schwierigkeiten aus dem Isogammenplan entnommen werden können. Es ist dazu allerdings erforderlich, die Isogammen recht sorgfältig und hinreichend eng zu zeichnen. Vielfach kann man bei Verwendung des üblichen Massstabes 1 : 25000 die Isogammen im Abstand von 0,2 mgal kartieren, um dann die Anomalienwerte zur Berechnung von g_{zz} auf 0,02 mgal interpolatorisch zu schätzen. Naturgemäss bedeuten die Kartierung der Isogammen aus den Messwerten eines Stationsnetzes sowie die anschliessende Interpolation bereits eine gewisse Glättung des Anomalienfeldes, die für die praktische Auswertung durchaus erwünscht ist.

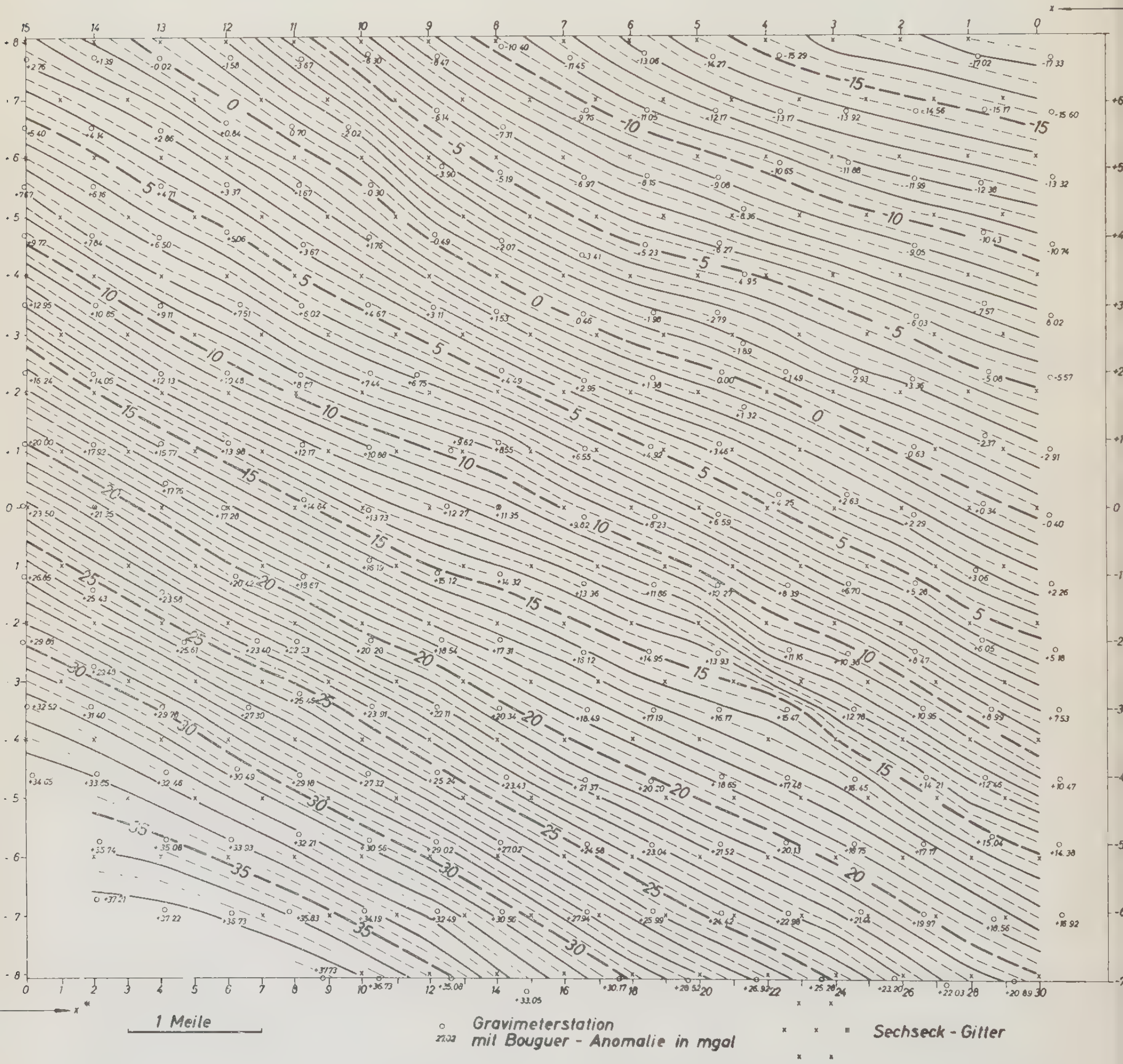

Fig. 4: Los Angeles Basin, California, Bouguer-Anomalien
(mit freundlicher Genehmigung der Gulf Research and Development Company, Pittsburgh, PA., USA)

Los Angeles Basin, California, Bouguer-anomalies
(Courtesy of Gulf Research and Development Company, Pittsburgh, PA., USA)

Im folgenden soll nun die Bearbeitung eines Messgebietes vorgelegt werden, in dem der regionale Schwereanstieg so stark ist, dass bei Kartierung im Massstab 1 : 25000 die Isogammen nur von 0,5 mgal zu 0,5 mgal gezeichnet werden können, d.h. die Anomalienwerte für die Berechnung von g_{zz} nur auf 0,05 mgal zu schätzen sind. Es handelt sich hierbei um das Los Angeles Basin, eines der von Elkins (1951) publizierten Anwendungsbeispiele. In Fig. 4 [1]) ist der Isogammenplan dargestellt, der aus den eingetragenen Messwerten gezeichnet ist, und zwar mit möglichst geringer „Generalisierung" des Isogammenverlaufs, die stellenweise wohl durchaus vertretbar gewesen wäre. Es sollte damit bewusst eine zu starke Glättung des Anomalienfeldes vermieden werden, um nicht willkürlich die g-Werte für die Errechnung von g_{zz} günstig zu beeinflussen. — Elkins legte seiner Berechnung von g_{zz} ein quadratisches Gitter der Kantenlänge $s = 1/2$ Meile zugrunde, dessen Koordinaten x, y am oberen und rechten Rand der Fig. 4 markiert sind. Um nun einige der im vorigen Abschnitt angegebenen Formeln zu prüfen, wurde das Messgebiet mit dem regelmässigen Sechseck-Gitter der Kantenlänge $s = 1/2$ Meile überdeckt, das in der Figur eingezeichnet ist; die Festlegung dieser Gitterpunkte erfolgt mit Hilfe der am unteren und linken Rand der Fig. 4 angegebenen Koordinaten x^*, y^* in der Weise, dass beide entweder geradzahlig oder ungeradzahlig sein müssen. Das Sechseck-Gitter ist so orientiert, dass seine Punkte $y^* = 0$; $x^* = 0, 2, 4, \ldots$ mit den Punkten $y = 0$; $x = 0, 1, 2, \ldots$ des quadratischen Gitters zusammenfallen.

Die Anomalienwerte g in den Punkten des Sechseck-Gitters, interpoliert aus den Isogammen, sind in Tab. 3 zusammengestellt. Diese Werte bilden die Grundlage der Berechnung von g_{zz} bei Verwendung der Formeln VIII, VI, III aus Tab. 2; die entsprechenden Ergebnisse sind in den Fig. 5-7 dargestellt.

Die Isanomalen von g_{zz} haben in den drei Fällen keineswegs das gleiche Aussehen. Fig. 5 zeigt ein ruhiges, ausgeglichenes Bild, das sich nur wenig von demjenigen in der grundlegenden Arbeit von Elkins (1951, S. 47) unterscheidet. In Fig. 6 ist die Streichrichtung *NW — SE* der Isanomalen noch deutlich vorherrschend, ihr Verlauf allerdings bereits ein wenig unruhiger. Hingegen ist in Fig. 7 die gravimetrische Wirkung von *NW — SE* streichenden Strukturen praktisch nicht mehr zu erkennen.

Vergleicht man diese Bilder mit der bekannten Lage der ölführenden Strukturen (Elkins, 1951, S. 46/47), so wird man zweifelsohne Fig. 5 den Vorzug geben, Fig. 6 allenfalls noch gelten lassen, Fig. 7 aber als unbrauchbar erklären. Ein generelles Urteil über die Brauchbarkeit der Formeln, mit deren Hilfe die drei Bilder berechnet sind, ist jedoch damit noch nicht gefällt, vielmehr muss

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[1]) Die Veröffentlichung der Fig. 4, der daraus erhaltenen Fig. 5-8 sowie der zugehörigen Diskussionen im Text geschieht mit freundlicher Genehmigung der Gulf Research and Development Company, Pittsburgh, P. A.

Tab. 3: Bouguer-Anomalien (multipliziert mit 100) in den Punkten x^*, y^* des Sechseck-Gitters, interpoliert aus den Isogammen der Fig. 4.

y^* / x^*	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
+ 8	220		085		055		200		420		655		865		1040		negativ
+ 7		370		235		080		090		270		520		730		890	
+ 6	650		520		375		230		060		115		380		580		
+ 5		790		645		515		370		205		010		215		400	
+ 4	1150		960		790		670		505		360		165		020		
+ 3		1320		1125		960		815		670		530		370		190	positiv
+ 2	1715		1500		1315		1140		980		850		735		585		
+ 1		1930		1720		1525		1350		1190		1065		950		810	
0	2330		2135		1920		1720		1550		1375		1265		1145		
— 1		2520		2325		2115		1925		1750		1580		1450		1350	
— 2	2890		2715		2525		2325		2150		1955		1795		1660		
— 3		3085		2930		2740		2565		2380		2180		2005		1845	
— 4	3360		3265		3120		2930		2760		2575		2390		2185		
— 5				3420		3285		3125		2950		2775		2580		2375	
— 6			3625		3570		3470		3330		3165		2990		2780		
— 7								3635		3515		3360		3180		2980	
— 8											3685		3535		3325		

y^* / x^*	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
+ 8	1170		1310		1440		1540		1620		1670		1740			negativ
+ 7		1035		1165		1285		1380		1450		1510		1570		
+ 6	730		860		970		1070		1190		1270		1330		1390	
+ 5		550		670		775		880		980		1060		1135		
+ 4	190		340		430		520		645		750		850		940	
+ 3		030		095		210		330		440		560		665		
+ 2	420		255		135		005		155		265		385		490	
+ 1		635		480		340		200		050		085		215		
0	980		835		680		515		360		230		075		050	
— 1		1215		1060		885		710		560		390		240		positiv
— 2	1530		1405		1290		1050		920		750		550		435	
— 3		1710		1585		1495		1275		1120		930		750		
— 4	2020		1880		1760		1665		1500		1300		1090		930	
— 5		2210		2065		1930		1805		1670		1480		1310		
— 6	2580		2405		2245		2115		1970		1820		1650		1520	
— 7		2775		2585		2425		2280		2135		1970		1820		
— 8	3140		2960		2800		2630		2470		2285		2130		2015	

man in dieser Hinsicht noch folgende Tatsachen betrachten: Die drei Formeln VIII, VI, III weisen nach der letzten Spalte von Tab. 2 wesentlich unterschiedliche Werte im mittleren Fehler auf. Das bedeutet aber auf Grund der diesbezüglichen Ausführungen in Abschnitt 3.1, dass Formel VIII die gravimetrische Wirkung der grossräumigen Strukturen gut erfassen kann und dass überdies noch ihre Ergebnisse durch die Streuung der g-Werte wenig beeinflusst werden. Andererseits gilt für Formel III die entgegengesetzte Aussage. In den von ihr gelieferten Isanomalen der Fig. 7 kommen daher vorwiegend die

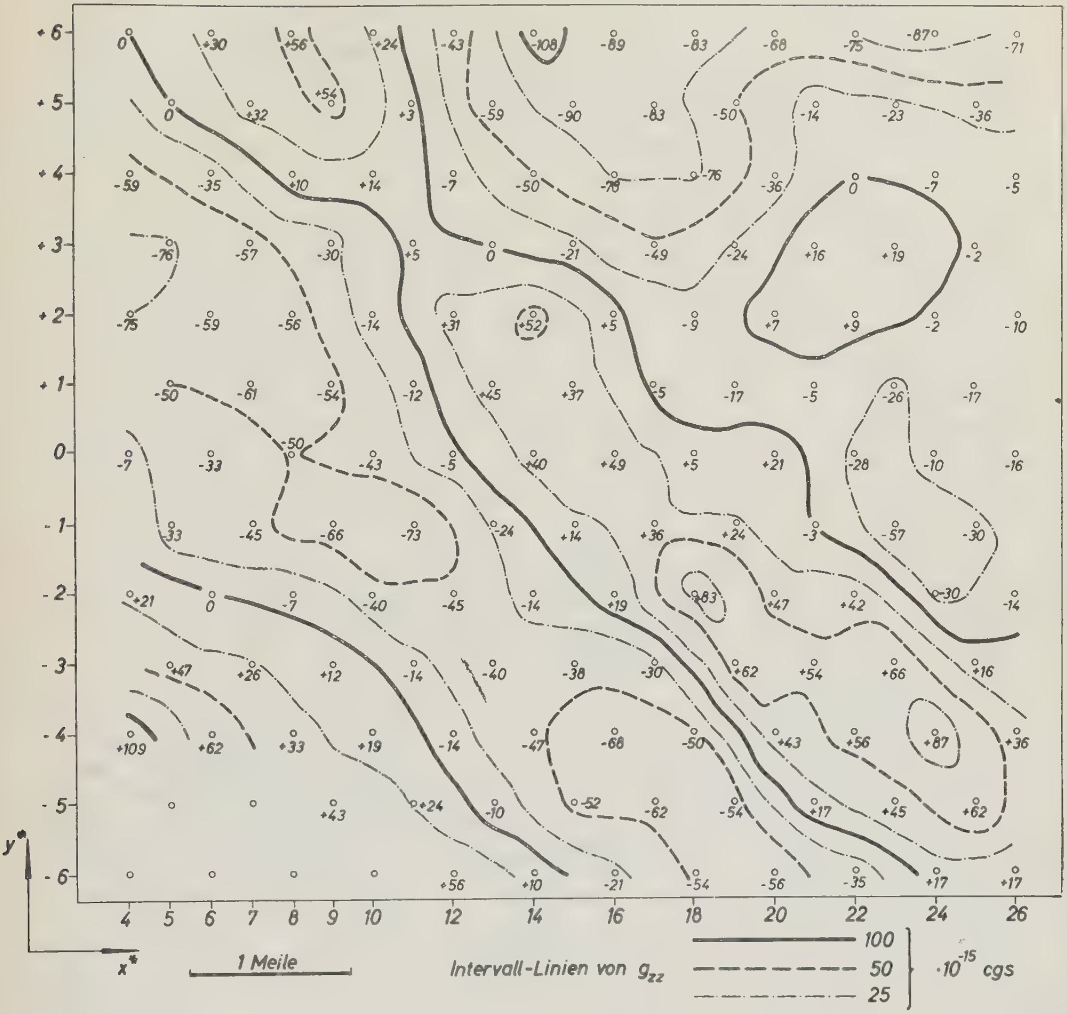

Fig. 5: Los Angeles Basin, g_{zz} nach Formel VIII
Los Angeles Basin, g_{zz} according to formula VIII

gravimetrischen Wirkungen höher gelegener Bauelemente der Kruste sowie Fehler in den g-Werten zur Abbildung. Rührt nun die Unruhe in Fig. 7 alleine von Fehlern in den g-Werten her? Diese Frage lässt sich mit Hilfe von Fig. 8 verneinend beantworten. Aus den beiden Kurven ergibt sich klar, dass innerhalb des grossräumigen Verlaufs der Anomalien im Bereich $3 \leqq x \leqq 5$, $-4 \leqq y \leqq -2$ eine zusätzliche gravimetrische Wirkung der Grössenordnung 1 mgal erkennbar ist, die wegen ihrer geringen Erstreckung nicht von jenen Bauelementen der Erdkruste herrührt, die das ruhige Bild in Fig. 5 hervorrufen.

Diese zusätzliche lokale Anomalie ist der Anlass für die starke Bewegung in den Werten von g_{zz} im entsprechenden Bereich der Fig. 7. Ähnliche, nicht so krasse Verhältnisse herrschen in der Umgebung des Punktes $x^* = 16$, $y^* = 0$ der gleichen Figur. Sind also neben der erdölgeologisch interessierenden, grossräumigen gravimetrischen Wirkung noch kleinräumige von genügender Intensität vorhanden, so darf man sich nicht wundern, wenn die Ergebnisse einer Formel mit grossem mittleren Fehler von letzteren stark beeinflusst werden. Vielmehr sollte man es nicht als selbstverständlich ansehen, dass eine

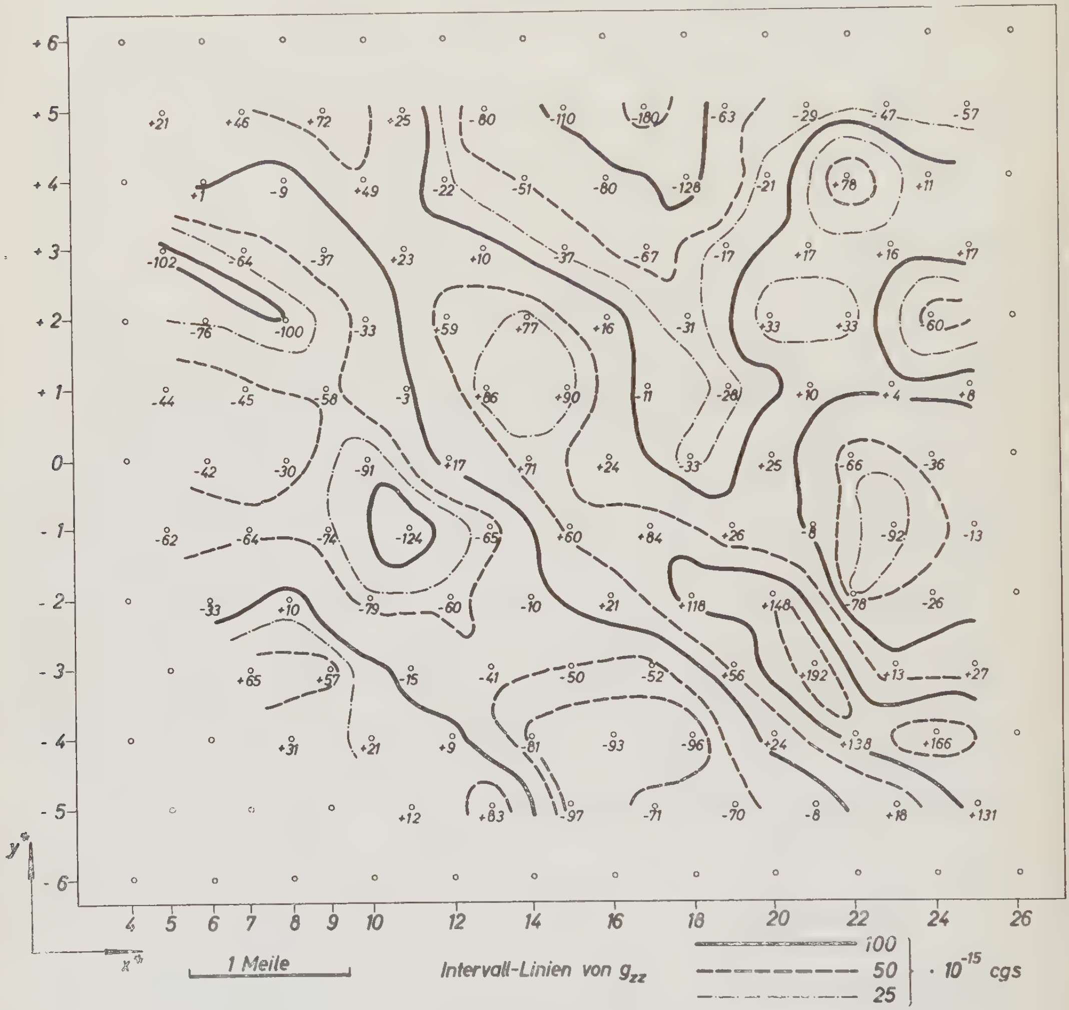

Fig. 6: Los Angeles Basin, g_{zz} nach Formel VI
Los Angeles Basin, g_{zz} according to formula VI

Formel mit kleinem mittleren Fehler, wie z.B. Formel VIII, eine lokale Anomalie vom Ausmass derjenigen im Gebiet $3 \leqq x \leqq 5$, $-4 \leqq y \leqq -2$ (vgl. Fig. 4 und 8) durch Glättung in ihrer Wirkung „unsichtbar" macht. — Nach diesen Überlegungen lässt sich in bezug auf ein Urteil über die Brauchbarkeit der

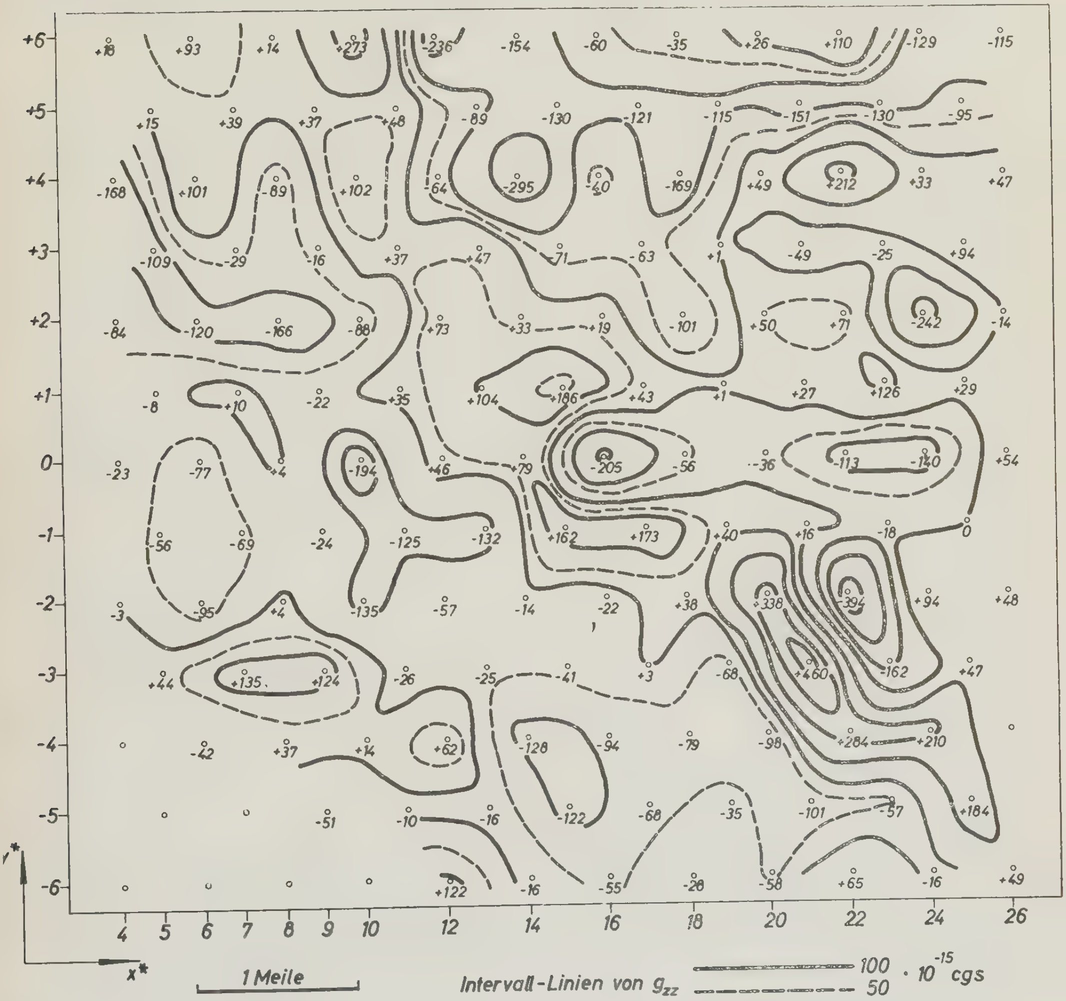

Fig. 7: Los Angeles Basin, g_{zz} nach Formel III
(Formel IV liefert praktisch das gleiche Bild)
Los Angeles Basin, g_{zz} according to formula III
(formula IV yields practically the same picture)

verschiedenen Formeln zusammenfassend folgendes sagen: Im Falle des Los Angeles Basin interessieren die grossräumigen Strukturen, die in Fig. 5 besonders günstig erkennbar sind. Es interessieren nicht die kleinräumigen, lokalen gravimetrischen Wirkungen, die erfreulicherweise bei Anwendung von Formel VIII praktisch nicht hervortreten. Jedoch verbietet das Vorhandensein dieser kleinräumigen, gravimetrisch wirksamen Bauelemente die Anwendung von Formel III. Wäre hingegen das Ziel der gravimetrischen Untersuchung nicht die Erkennung der grossräumigen Bauelemente, sondern der kleinräumigen von der Grössenordnung desjenigen im Gebiet $3 \leqq x \leqq 5$, $-4 \leqq y \leqq -2$, so wäre Formel VIII für diesen Zweck absolut ungeeignet, möglicherweise auch noch Formel III. Voraussichtlich würde ein Versuch mit einer der Formeln III, IV oder VI zufriedenstellend verlaufen, wenn die Kantenlänge *s* des Gitters geeignet kleiner gewählt wird; das setzt allerdings eine engere Vermessung des fraglichen Gebiets und seiner Umgebung sowie eine genauere Arbeitsweise bei der Interpolation voraus.

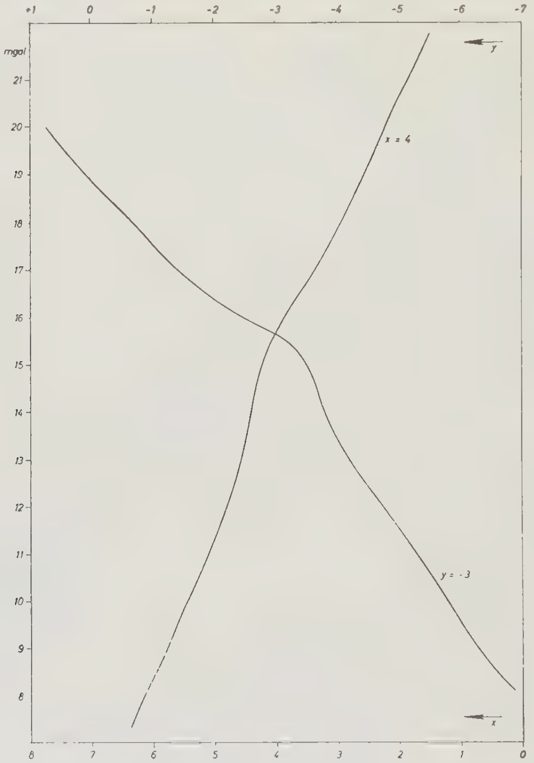

Fig. 8: Bouguer-Anomalien auf zwei Profilen entlang x = 4 und y = -3 aus dem Isogammenplan der Fig. 4

Bouguer anomalies along two profiles (x = 4 and y = -3), drawn from the isogram map of fig. 4.

Hiermit werde die Diskussion über die Bearbeitung des Anomalienfeldes im Los Angeles Basin beendet; die Ergebnisse derselben sind jedoch noch wesentlich für die im nächsten Abschnitt zu behandelnde Frage nach der Vergleichbarkeit verschiedener Näherungsformeln für die zweite Ableitung.

3.3 Über die Vergleichbarkeit verschiedener Näherungsformeln für die zweite Ableitung.

Nach den allgemeinen Entwicklungen im Abschnitt 2.4 existiert eine unübersehbare Mannigfaltigkeit von Näherungsformeln zur Berechnung der zweiten Ableitung. Für die Zwecke der Praxis allerdings genügen einige wenige, die man sich auf Grund ihrer speziellen ,,Eigenschaften'' auswählen muss. Die Auswahl kann erheblich erleichtert werden, wenn man weiss, nach welchen Gesichtspunkten verschiedene Formeln miteinander zu vergleichen sind. — Ein anschauliches Beispiel einer solchen Auswahl bilden die Fig. 5-7. Obwohl die dort benutzten Formeln VIII, VI und III formal Näherungsausdrücke für die gleiche Grösse g_{zz} darstellen, sind ihre Ergebnisse zum Teil extrem verschieden. Die Gründe hierfür sind im vorigen Abschnitt dargelegt; sie zeigen, dass eine absolute Bewertung von Näherungsformeln für die zweite Ableitung gar nicht möglich ist, sondern dass es darauf ankommt, welcher Typus einer gravimetrischen Wirkung erkannt werden soll. Das bedeutet gleichzeitig, dass die Frage nach der Existenz einer universal verwendbaren Formel, die allen praktischen Erfordernissen gerecht werden kann, verneint werden muss.

In Abschnitt 3.2 wurde zur Erklärung der unterschiedlichen Bilder das Unterscheidungsmerkmal des mittleren Fehlers der benutzten Formeln herangezogen. Hiernach wie aus weiteren Erfahrungen lässt sich allgemein folgendes sagen: Liegt s in der Grössenordnung von 1 km, so sind Formeln mit einem mittleren Fehler von 0,5 — 1 x E/s^2 zur Lokalisierung grossräumiger, tiefer liegender Strukturen besonders geeignet, wohingegen solche mit einem mittleren Fehler über ca. 4 E/s^2 zur Erkennung kleinräumiger, höher liegender Strukturen brauchbar sind.

Formeln mit *gleichem* mittleren Fehler liefern jedoch nicht völlig gleichartige Ergebnisse. Vielmehr spielt dabei noch eine gewisse Rolle, in welchem Masse die Koeffizienten einer Formel abnehmen, wenn sie wie in (15) im Sinne wachsender r_j angeordnet werden. Es wird offenbar durch die Abnahmerate der Koeffizienten das ,,Einflussgebiet'' des Anomalienfeldes auf den Näherungswert von g_{zz} reguliert.

Auf den folgenden Punkt muss noch besonders hingewiesen werden: Es empfiehlt sich nicht, Formeln *ohne* g^P mit *grossem* mittleren Fehler, z.B. Formel X in Tab. 2, in der Praxis zur Lokalisierung kleinräumiger Strukturen zu benutzen. Das Fehlen von g^P wirkt sich im allgemeinen ungünstig auf die Deutbarkeit des g_{zz}-Bildes aus. Es ist also nicht ratsam, solche Formeln zu einem Vergleich mit anderen heranzuziehen, deren mittlerer Fehler in der gleichen Grössenordnung liegt.

Zum Abschluss dieses Abschnitts werde noch auf den früheren Versuch eines Vergleichs von Formeln für die 2. Ableitung eingegangen, der im Rahmen der Diskussion zu einer Arbeit des Verfassers (Rosenbach, 1953, S. 907-912) angestellt wurde. Die Vergleichsergebnisse der Fig. A (S. 908) einerseits und der Fig. B (S. 910/911) andererseits schienen diametral entgegengesetzt zu sein. Im Lichte der vorstehenden Betrachtungen muss man jedoch sagen, dass die Ergebnisse in den beiden Vergleichsfällen gar nicht anders sein konnten: Es haben nämlich die beiden miteinander verglichenen Formeln mittlere Fehler, die sich wie 1 : 5 verhalten. Zum Zwecke des Vergleichs wurden sie im Falle der Fig. A auf ein Anomalienfeld angewandt, in dem ausser dem Regionalanstieg nicht nur die gravimetrische Wirkung der interessierenden grossräumigen Struktur, sondern auch diejenige kleinräumiger Bauelemente vorhanden war; im Falle der Fig. B hingegen erfolgte eine Anwendung beider Formeln auf ein Anomalienfeld, aus dem die gravimetrische Wirkung einer kleinräumigen Struktur erkannt werden sollte. – Hiernach liegt es also in der Natur der Sache, dass die beiden Vergleichsergebnisse als einander entgegengesetzte Aussagen erscheinen.

3.4 Einige Hinweise zur routinemässigen Bearbeitung praktischer Messergebnisse.

Den Näherungsformeln für g_{zz}, die in den Abschnitten 3.1 und 3.2 diskutiert wurden, lag ein regelmässiges Sechseck-Gitter zugrunde. Die Verwendung eines solchen hat in der Praxis den Vorteil geringer Ablesearbeit, wie bereits in Abschn. 2.4 zum Ausdruck gebracht wurde. Ein weiterer Vorteil ist nunmehr dadurch gegeben, dass mit wenig zusätzlichem Arbeitsaufwand verschiedene Formeln aus Tab. 2 angewandt werden können, sobald die Summen aus (15) berechnet vorliegen. Auf diese Weise liesse sich in manchen Fällen ein Gewinn für die Interpretation der Messergebnisse erzielen, wenn geologische Bauelemente verschiedener räumlicher Erstreckung zu erwarten sind.

Auf Grund der theoretischen Überlegungen in Abschn. 2.3 ist die Verwendung eines regelmässigen Sechseckgitters nur bei solchen Formeln sinnvoll, für deren Herleitung die entsprechenden Polynome von der 4. Ordnung sind. Damit wird aber auch den Erfordernissen der Praxis normalerweise genügt werden können. – Nach den Ausführungen in 2.3 besitzen derartige Formeln „drehungsinvariante" Koeffizienten; die damit errechneten Werte von g_{zz} sind aber trotzdem abhängig von starren Drehungen der zugrunde liegenden Punktkonfiguration, was eine Folge der entsprechenden Abhängigkeit der $\bar{g}_n(r_j)$ ist. Will man diese Abhängigkeit des Ergebnisses von der Orientierung der Punktkonfiguration praktisch bedeutungslos machen, so kann das durch eine Erhöhung der Punktezahl pro Kreis erreicht werden. Dann ist jedoch nicht mehr die Verwendung eines regelmässigen Gitternetzes möglich, so dass also der Arbeitsaufwand erheblich grösser wird.

Der Autor dankt Herrn Dr. Leo J. Peters von der Gulf Research and Development Company, Pittsburgh, P.A., U.S.A., verbindlichst für die Freigabe des Materials aus dem Los Angeles Basin. — Ebenso dankt er der Fa. PRAKLA, Gesellschaft für praktische Lagerstättenforschung G.m.b.H., Hannover, für die gewährte Förderung zur Durchführung der Untersuchung.

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Discussion

V. Baranov (written discussion):

Le calcul de la seconde dérivée verticale est un problème très simple et déjà résolu. Cependant, la mise au point de Dr Rosenbach montre que certains détails continuent à présenter un intérêt et méritent attention. Je saisis donc cette occasion pour formuler quelques observations.

Dans le § 2.3. Dr. Rosenbach utilise le développement le *g* en une double série de Taylor au voisinage de l'origine *P*, pour représenter la valeur de *g* au point *A* (fig. 2) qui peut se trouver assez loin de *P*, par exemple, à une dizaine de kms. On peut se demander si un tel procédé est légitime. En effet, le champ *g* est théoriquement analytique. Mais pratiquement cette fonction ne doit pas être considérée comme analytique. Une anomalie, même intense, mais localisée dans la région du point *A*, ne se fait que faiblement sentir au point *P*. Son action à l'origine sera alors inférieure aux erreurs expérimentales. Par conséquent, il semble douteux qu'on puisse représenter l'anomalie au point *A* en

partant de l'origine. Il existe pourtant une méthode beaucoup plus simple, d'ailleurs bien connue, pour évaluer l'erreur qu'on commet en remplaçant l'intégrale par une somme. Je la rappelle ici brièvement.

La fonction $g(r, \varphi)$ est périodique sur le cercle de rayon constant; elle peut donc être développée en une série de Fourier

$$g\,(r,\,\varphi) = A_0 + \sum A_k \cos k\varphi + \sum B_k \sin k\,\varphi$$

d'où

$$\bar{g}\,(r) = \frac{1}{2\pi} \int g\,(r,\varphi\,)\,d\varphi = A_0$$

Prenons les angles φ_ν en progression arithmétique $\alpha + \frac{2\pi\nu}{N}$
et faisons la somme

$$g\,(r,\,\varphi_\nu) = NA_0 + \sum A_k \sum \cos k\,\varphi_\nu + \sum B_k \sum \sin k\varphi_\nu$$

Le calcul des sommes trigonométriques qui interviennent dans cette expression est très simple. On obtient le résultat suivant:

$$\begin{aligned} g\,(r) = g\,(r) - A_N \cos N\alpha - A_{2N} \cos 2N\alpha - \ldots \\ - B_N \sin N\alpha - B_{2N} \sin 2N\alpha - \ldots \end{aligned}$$

On voit donc qu'en remplaçant $\bar{g}\,(r)$ par $\dot{g}\,(r)$ on néglige l'harmonique d'ordre N, — nombre de points de subdivision. L'amplitude de cet harmonique est $\sqrt{(A_N^2 + B_N^2)}$. Elle est indépendante de l'angle, c'est-à-dire de l'orientation des axes Oxy.

Il n'est d'ailleurs nullement indispensable de remplacer de cette façon l'intégrale par une somme. En effet, une fois le champ échantillonné à l'aide d'une grille quelconque, on peut tracer n'importe quelles droites et n'importe quels cercles passant ou ne passant pas par les points canoniques de la grille et calculer les intégrales et les dérivées avec une précision qui ne sera limitée que par le pas de la grille et par les erreurs expérimentales. Dans le § 2.4. Dr. Rosenbach a établi une douzaine de formules et a calculé l'erreur moyenne dont la valeur figure dans le tableau 2. Il est bien évident que ces valeurs ne sauraient caractériser la précision. Prenons, par exemple la formule VII. Elle comporte 12 termes et le coefficient de chaque terme est 1/3. Pour calculer l'erreur moyenne, on extrait la racine carrée de la somme des carrés des coefficients ce qui donne 1,15. Supposons maintenant qu'au lieu de prendre seulement six points sur chacun des deux cercles A et B, nous prenions un grand nombre N points. La formule devient:

$$g''_{zz} = \frac{2}{N} \sum_{1}^{N} g\,(A) - \frac{2}{N} \sum_{1}^{N} g\,(B)$$

Elle comporte $2N$ termes et les coefficients sont $2/N$. L'erreur moyenne devient $\sqrt{8/N}$. Elle tend donc vers zéro lorsque N augmente. Ceci est évidemment inexact.

Cette question de la précision du calcul de la seconde dérivée n'a pratiquement aucune importance. En effet, ce que nous cherchons, c'est à supprimer l'anomalie régionale et à accentuer les anomalies résiduelles, tout en évitant dans la mesure du possible d'exagérer l'influence des erreurs expérimentales. Une formule pratique est toujours un compromis entre ces tendances contradictoires. L. J. Peters et T. A. Elkins ont très bien souligné ce fait dans leur discussion avec Dr Rosenbach en 1953.

O. Rosenbach (reply):

Die Diskussion von Herrn Dr. Baranov ist sehr interessant, allerdings berührt sie nur wenig den eigentlichen Inhalt der Arbeit.

Die Verwendung eines Taylor-Polynoms als analytisches Bildungsgesetz von g bedeutet eine Extrapolation, die naturgemäss um so schlechter wird, je grösser $r = PA$, zumal wenn bei A noch eine lokale Anomalie vorhanden sein soll. Da die hierzu gehörigen Überlegungen in den §§ 2.2 und 2.3 $\dot{g}_n\ (r)$ betreffen, ist die Berechtigung dieses Ansatzes in gleicher Weise gegeben wie desjenigen für $\bar{g}\ (r)$ in (2), der sich mit ein wenig modifizierter Herleitung bereits bei Elkins findet. Im übrigen ist es für die formalen Entwicklungen der §§ 2.3 und 2.4 nicht wesentlich, ob sich eine lokale Anomalie in A von P aus in der angegebenen Weise genau darstellen lässt, denn das Ziel ist ja nicht eine möglichst gute Darstellung der ,,wahren'' 2. Ableitung, die als Hilfsmittel bei der gravimetrischen Interpretation wohl keinen allzu grossen Dienst leisten würde. Vielmehr kommt es darauf an, brauchbare Näherungsformeln für die verschiedenartigen Aufgaben der Praxis zu ermitteln, was mit Hilfe des gewählten Ansatzes erreicht werden kann, wie Abschnitt 3 dieser Arbeit und weitere Ergebnisse zeigen.

Die von Herrn Dr. Baranov angegebene Methode zur Berechnung des Fehlers, den man bei der Ersetzung des Integrals durch eine Summe begeht, hat keine Beziehung zu den von mir angestellten Überlegungen, da ich auf diesen Fehler gar nicht eingegangen bin. Insbesondere hat die Unabhängigkeit der Amplitude der Harmonischen von der Ordnung N nichts mit der von mir diskutierten Drehungsinvarianz der Koeffizienten in dem Näherungspolynom für $\dot{g}_n(r)$ zu tun.

Weiterhin ist die Beanstandung hinfällig, dass der angegebene mittlere Fehler $\sqrt{8/N}$ mit wachsendem N gegen Null geht. In der von Herrn Dr. Baranov angegebenen Formel darf nämlich zwischen g_{zz} und der rechten Seite nicht das Zeichen $=$ stehen, sondern dort muss das Zeichen $\approx$ verwendet werden. Nunmehr gibt der mittlere Fehler im Sinne der Statistik den Einfluss der Fehler der g-Werte auf die rechte Seite an; er wird auch „Funktionsfehler" genannt. Hieraus folgt, dass mit wachsendem N die rechte Seite gegen einen Ausdruck strebt, der aus dem vorliegenden dadurch entsteht, dass man $\dot{g}_N(A)$ bzw. $\dot{g}_N(B)$ durch $g(A)$ bzw. $g(B)$ ersetzt; dabei muss zwangsläufig der mittlere Fehler der rechten Formelseite mit wachsendem N gegen Null gehen. – Damit ist andererseits noch gar nichts über die Approximation des wahren Wertes von g_{zz} durch die rechte Seite der Formel ausgesagt.

Hiernach trifft offensichtlich auch nicht die von Herrn Dr. Baranov vertretene Meinung zu, dass die Arbeit die Frage nach der Genauigkeit der Berechnung der 2. Ableitung zum Gegenstand hat. Vielmehr verfolgen die Ausführungen in Abschnitt 3 gerade das Ziel, den mittleren Fehler einer Formel als gewisses quantitatives Charakteristikum heranzuziehen, und zwar in dem Sinne, ob die Formel evtl. den erwünschten Kompromiss zwischen den von Herrn Dr. Baranov treffend benannten gegenläufigen Tendenzen bei der praktischen Bearbeitung herbeiführen kann. Im übrigen erfolgten diese Überlegungen gerade mit Hinblick auf die Diskussionsbemerkung der Herren Dr. L. J. Peters und T. A. Elkins.

ON THE BEHAVIOUR OF A WORDEN GRAVIMETER FOR PERIODICAL VARIATIONS IN EXTERNAL TEMPERATURE AND RAPID VARIATIONS OF PRESSURE *)

BY

MICHELE CAPUTO **)

ABSTRACT

1. A Worden gravity meter has been tested for sinusoidal variations in the external temperature, by determining simultaneously the corresponding variations of temperature inside the Dewar vacuum bottle, and the variations in the readings.

A second Worden gravimeter has been tested for rapid variations in external pressure.

During the Italian Karakorum Expedition in the years 1954 and 1955, Prof. Antonio Marussi, in charge of geophysical exploration in the Expedition, made an extensive gravimetric survey in the Karakorum Range, using Worden gravimeters No. 6 and No. 203. Prof. Marussi (1956) has already given a preliminary account of his survey which connects, in this highest part of Asia, the Indian with the Russian governmental gravity nets.

In that region, there are large diurnal variations of temperature during the summer, and moreover the instrument underwent a wide range of pressure variations due to the rugged nature of the country. In order to determine how variations of temperature influence the gravimeter readings, Prof. Marussi proposed some experiments which were carried out in the early months of 1955 with gravimeters No. 6 and No. 203, as well as with other gravimeters, by Drs. Cunietti and Inghilleri (1956) of the *Politecnico di Milano*. Other experiments to determine the influence of pressure variations in the readings were performed on meter No 6, with the collaboration of the *Istituto di Macchine* of the *Politecnico di Torino*. In June 1955, gravimeter No. 203 had to be repaired in consequence of a severe shock, and the instrument had to be retested. On this occasion, new experiments, reported in this paper, were performed. Reference is also made to the pressure-test to which gravimeter No. 6 was subjected.

1. As is well known, in the Worden gravimeters the quartz system is placed in a Dewar vacuum bottle in order to reduce the influence of rapid variations

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*) Presented at the Eleventh meeting of the E.A.E.G., held in Milan, 12-14 December 1956.

**) Istituto di Topografia e Geodesia, Università degli Studi, Trieste.

of temperature (Morelli, 1951). Moreover, the instrument is equipped with a temperature compensating system which keeps the variations of the readings due to the temperature changes within limits which are generally satisfactory. The vacuum bottle damps out the effect of external diurnal temperature variations. The aims were to determine the time lag and reduction of amplitude and also to examine the resulting variation in the meter readings.

Experiments on the first objective were performed in cooperation with Prof. Poiani and Dr. Gabrielli of the *Istituto di Fisica* of the *Università di Trieste,* to whom we are very much indebted.

2. The apparatus constructed by the Istituto di Fisica consisted of a temperature controlled enclosure of 60 × 70 × 100 cm in which the gravimeter was placed, an automatically controlled heater giving a sinusoidal variation of temperature, and a thermo-couple situated inside and at the bottom of the vacuum bottle.

To observe the position of the beam, the microscope and cross wires were removed and placed at one end of a tube 16 cm in length. A convex lens 4 cm. in focal length was placed in the centre of the tube so that readings could be made while the meter was in the thermostatic cell. The small dial was rotated from outside by means of a rod. Two small windows in the cell permitted the reading of the small dial and of a thermometer, using two mirrors placed on the top of the gravimeter; the levels of the instrument could be checked.

3. *Drift for periodical variations of temperature.* The first experiment was made by varying the temperature outside of the gravimeter sinusoidally with a period of 24 hours and between 24.2°C and 33.8°C. The temperature inside the vacuum bottle was obtained with the thermocouple, and a recording galvanometer. The small dial was read every hour.

The results of this first experiment are presented in Fig. 1; curve (1) shows the readings corrected for tidal effects; curve (7) the temperature inside the main enclosure, and curve (6) the temperature inside the gravimeter.

From the temperature curves it can be seen that an external periodical variation of temperature of 9.6°C is transferred to the inside of the vacuum bottle with a mean delay of 5.5 hours, and that the amplitude is reduced to 2.2°C. The shape of the curve of the internal temperature is, moreover, perfectly sinusoidal.

In curve (1) showing the gravimeter readings, a constant drift is superimposed on the periodical effect. To determine the constant drift, the derivative curve of (1) was constructed, and its mean value was found to be 0.035 mgal/hour. By subtracting this hourly drift from curve (1), curve (2), which represents the periodical component, is obtained.

If we assume a linear relation between the external temperature and the effect on the gravity readings due to the parts of the gravimeter which are

Annexed to the paper: on the behaviour of a worden gravimeter for periodical variations in exterior temperature and rapid variations of pressure by Michele Caputo, Università — Trieste

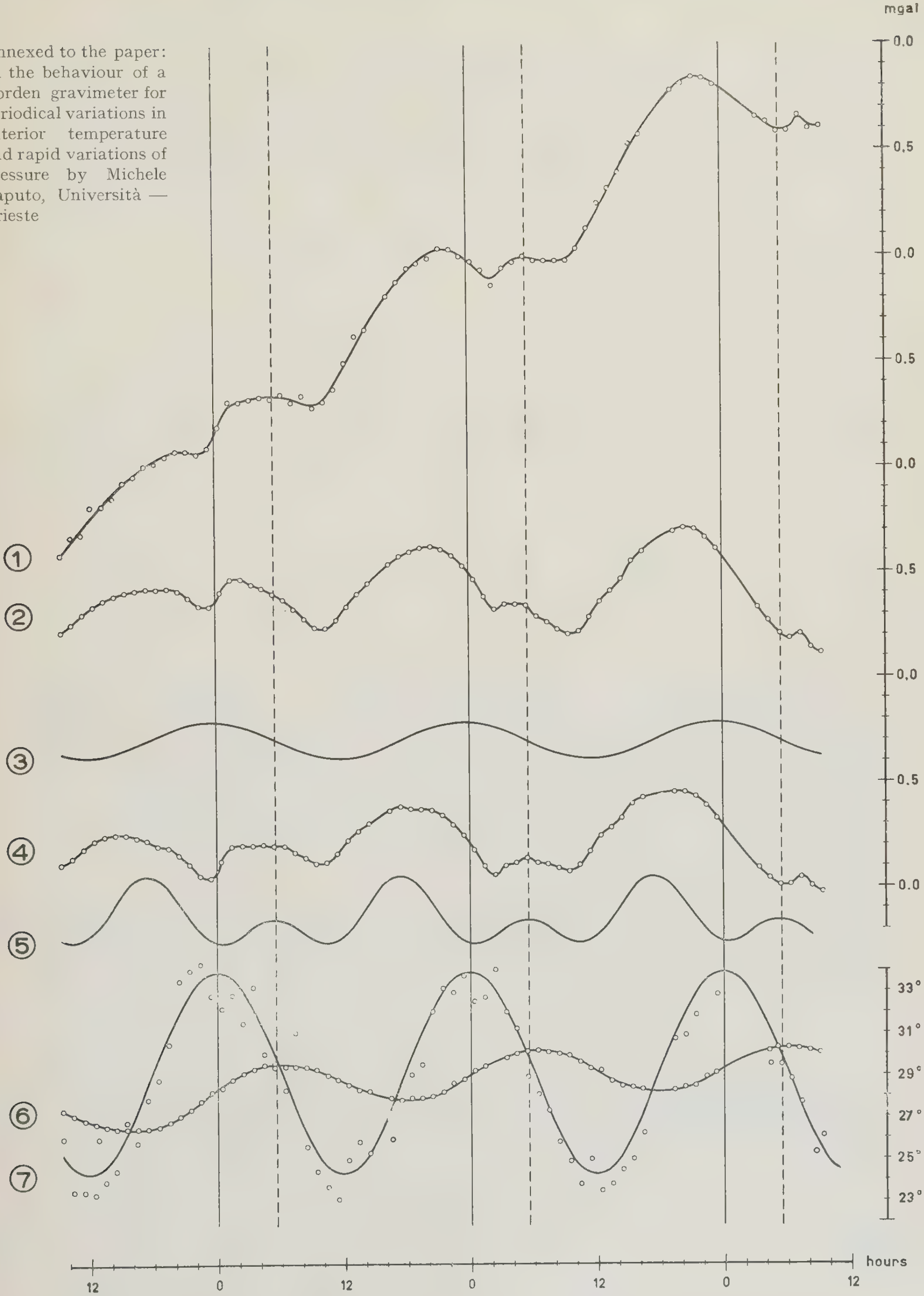


Fig. 1. Response of Worden gravimeter to periodical changes in temperature

not protected by the vacuum bottle, a sinusoidal correction (curve (3)) in phase with the external temperature should first be applied to the readings. This correction is chosen so that the residual variation of the readings, curve (4), represents a periodical variation in phase with the internal temperature. This residual variation is assumed to be due in part to the quartz system (and its temperature compensation) which are protected by the vacuum bottle.

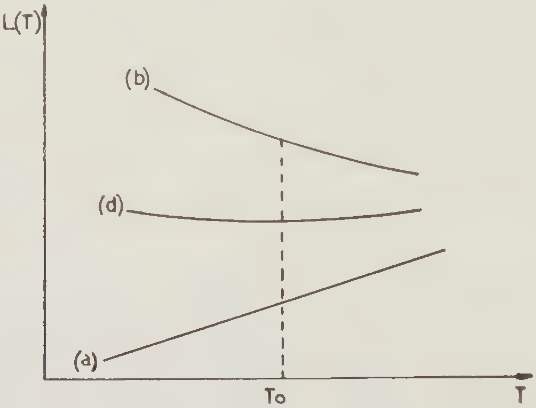


Fig. 2. Illustrating the effect of the temperature on the quartz system and on the temperature compensating system

Curve (4) has a peculiar shape, which is probably due to the effect of the temperature compensating system, and which may be explained as follows. Curve (4) represents two simultaneous effects: deformation of the quartz spring and the temperature compensating system. Assuming that the deformation of the quartz system is a nearly linear function of temperature, as indicated in figure 2 (curve a), and that the temperature compensating system has a non-linear effect as indicated in the same figure (curve b), then the resultant curve (d) will have a stationary value at a certain temperature, say T_0. In the neighbourhood of this point the response L of the gravimeter will therefore be proportional to the square of the difference between the actual temperature and T_0, i.e.

$$L(T) = L\,(T_0) + \frac{L''(T_0)}{2}(T - T_0)^2 + \dots \tag{1}$$

by Taylor's expansion.

For periodical variations of the interior temperature in the range $T_1 > T_0 > T_2$,

$$T = T_M + T_{1,2} \sin \frac{\pi\, t}{12}$$

where:

$$T_M = \frac{T_1 + T_2}{2}, \; T_{1,2} = \frac{T_2 - T_1}{2}$$

and t is the time, we have

$$y = \alpha\left(T_M - T_0 + T_{1,2} \sin\frac{\pi t}{12}\right)^2 = \bar{\alpha}\left(\sin\frac{\pi t}{12} + \bar{\beta}\right)^2 \tag{2}$$

in which

$$y = L(T) - L(T_0), \qquad \alpha = \frac{L''(T_0)}{2},$$

$$\bar{\alpha} = \alpha T_{1,2}^2, \qquad \bar{\beta} = \frac{T_M - T_0}{T_{1,2}}.$$

The values of the constants $\bar{\alpha}$ and $\bar{\beta}$ giving the best approximation to curve (4) are $\bar{\alpha} = 0.2013$ and $\bar{\beta} = -0.261$; the theoretical curve is represented by (5) in Fig. 1. Taking these values for $\bar{\alpha}$ and $\bar{\beta}$, and since $T_M = 29.2$ and $T_{1,2} = 1,1$ we have:

$$T_0 = + 1.1 \times 0.26 + 29.2 = 29.5$$

4. *Ratio of the scale constants of the two dials and sensitivity at various temperatures*

Tests were performed by keeping the instrument at a constant temperature for a long time in order to assure complete stabilization of the internal and external temperatures. Two tests were made during the period of stabilization of the interior temperature, and further three tests after stabilization was completed. For the first two tests, the time variation of the internal temperature was observed for a constant external temperature. The relation found experimentally can be represented with sufficient accuracy by the formula.

$$T = \Theta^* + (T^* - {}^*\Theta)\, e^{\frac{-t}{12}} \tag{3}$$

where Θ^* and T^* are the initial external and internal temperatures respectively and T the interior temperature at the time t. By means of (3) the interior temperature of the instrument during the observations was estimated with adequate accuracy for the present purpose. To calculate the ratio R of the dial constants we applied the following method (Caputo, 1957).

Let L_i be the reading on the large dial, l_i the corresponding reading on the small dial, n the number of observations, R the ratio of the scale constant of the large dial to that of the small dial, and x the hypothetical reading on the small dial when the reading on the large dial is zero. The relation between the l_i's and the L_i's can be approximated by a linear function

$$l = L R + x \tag{4}$$

where l and L are the values of the l_i and L_i adjusted to this linear relation. Introducing the notation

$$\bar{L} = (\Sigma L_i)/n \text{ and } L_i^* = L_i - \bar{L}$$

equation (4) may be written

$$l = L^* R + \bar{L} R + x$$

By the method of least squares the value of R and its mean square error, η, may be obtained (Caputo 1957). This leads to

$$R = \frac{\Sigma(l_i L_i^*)}{\Sigma(L_i^{*2})} \text{ and } \eta = \frac{1}{R} \sqrt{\frac{\Sigma(l_i^2) - \frac{\Sigma(l_i^2)}{n} - \frac{(\Sigma L_i^* l_i)}{\Sigma(L_i^{*2})}}{(n-2)\Sigma(L_i^{*2})}}$$

The calculated values of R and the standard deviation are given below.

Date	Temp.	R	$\eta 10^3$
30/ X/56	19°C	50.928	1.4
31/ X/56	25°C	51.004	2.4
5/XI/56	18°C	50.940	1.6
7/XI/56	25°C	51.030	1.2
8/XI/56	2°C	50.729	1.2

With these values, the graph in Fig. 3, showing R as a function of temperature, has been drawn.

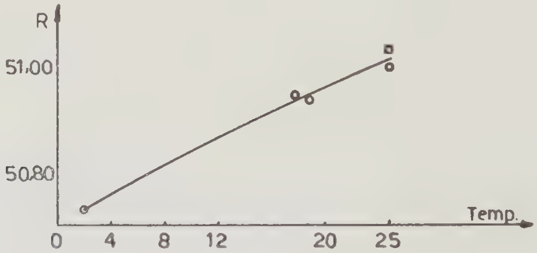


Fig. 3. Relation between the temperature and the ratio between the dial constants

For the sensitivity, expressed in units of the small dial required to move the beam from the centre line to an outside line, the values shown in the following table were obtained.

Date	Temp.	Sensit.
30/ X/56	18°C	36.7
31/ X/56	26°C	39.9
8/XI/56	2°C	35.4

5. *Influence of pressure.* Only a few words need be said about the pressure test to which gravimeter No. 6 has been submitted.

The experiment was performed in the decompression chamber of the *Istituto di Macchine* of the *Politecnico di Torino.* The pressure was varied abruptly from a value corresponding to an elevation of 200 m (height of Turin) to that of 2500 m and later from 2,500 m to 5,000 m and back in about four hours. During this time, the variation of temperature was 2.5°C. Obviously the variation of temperature is mainly due to the adiabatic effect of the pressure changes, and for this reason its effect on the meter was not delayed by the vacuum bottle. The effect of temperature variation must therefore not be neglected and the interpretation of the two superimposed effects, pressure and temperature variations, is rather difficult. We can only say that during these variations the gravimeter showed abrupt changes in the readings up to 0.5 mgal, and in some cases the changes were permanent.

This test proved that in gravity links of high accuracy made with an instrument carried by air, the instrument must be kept inside a pressurized cabin, in order to avoid such abrupt and possibly permanent changes in the readings.

Discussion

A. Schleusener: If I understood you correctly the period of the temperature variations is about 5.5 hours. In this case there should be visible a delay time of about 40 to 50 minutes between the first change of temperature outside the gravimeter and the readings of the gravimeter.

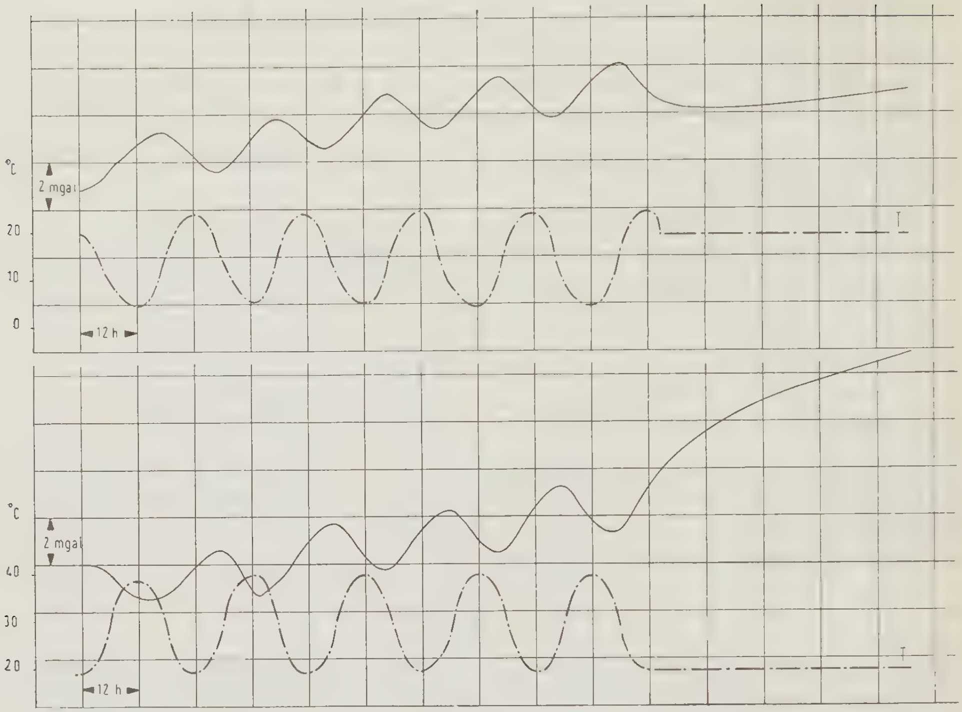
I have the impression that this delay time cannot be seen in curve No. 7.

M. Caputo: The period of the temperature variation is about 24 hours and the delay time between the interior and external temperatures is about 5.5 hours, as we can see in the curves Nos. 6 and 7. The curve No. 4 is in phase with the curves Nos. 6 and 5 and has a delay time of 5.5 hours with the external temperature.

M. Cunietti: You have heard from Mr. Caputo that in the Institute of Geodesy of the Politecnico di Milano some experiments have been performed by Mr. Inghilleri and myself to find the relationship between drift of five Worden gravity meters and temperature changes. The results of this work have already been published in ,,Bollettino di Geodesia e Scienze affini'' of the Italian Geographical Institute.

One of the purposes of these experiments was to determine the correlation between drift of Worden gravity meters and temperature changes, when the temperature variations are sinusoidal, with a period of twenty four hours and an amplitude of twenty degrees centigrade.

According to our results, drifts are not in phase with the temperatures, and often the former are anticipated. These results and the others obtained in the



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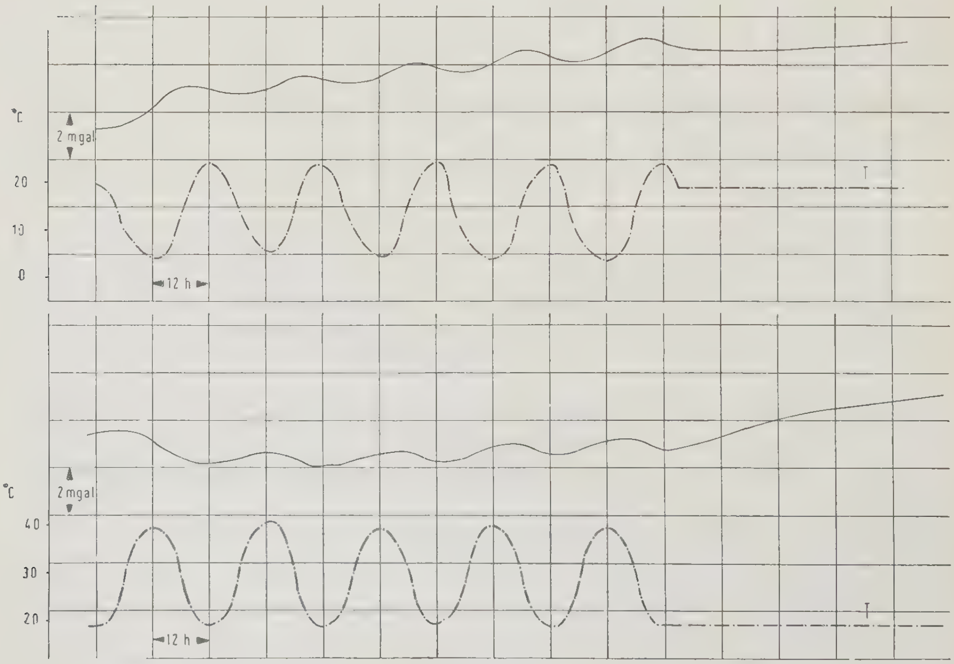

Number 91

same study led us to the conclusion that in Worden gravity meters there are two parts which are influenced at different times by temperature variations. The first one consists of the devices situated near the top of the Dewar bottle, which are affected immediately by temperature changes; the second follows the same variations a few hours later. These conclusions are in accordance with the results reached by dr. Caputo.

It is also important to note that in the recently built gravity meters the drift is noticeably smaller than in the older ones. The figures show the drift curves of the gravity meters numbers 6 and 91.

In our paper we have suggested some precautions in the use of Worden gravity meters derived from our experiments.

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Among the recent advances, specially mentioned are: the new weight-dropping seismic technique, the high-frequency seismic instruments, magnetic recording methods, the continuous velocity logger, the nuclear magnetometer, the optical analog computer and the gravity anomaly simulator.

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The applied geophysics section provides laboratories for research on techniques and instruments for magnetic, gravitational, seismic and electrical prospecting. Facilities are provided for instrument testing and model experiments.

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It is pointed out that modern exploration techniques, including concentrated use of geophysics, are being applied with considerable success in the Gulf of Mexico. Past experience has shown that in some less advanced countries, where roads & settlements are few and widely spaced, the cost of offshore development is lower than that on land. It has been shown that unit seismic operation costs in marine areas are approximately one third of those on land.

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210. *Continuous Velocity Logging.*
World Petroleum, Vol. 27, No. 3, pp. 91-93, March, 1956.
A brief general article describing the continuous velocity logger and its use in seismic prospecting for oil.

211. *Refraction Revival.*
R. W. Olson, World Petroleum, Vol. 27, No. 3, pp. 69-71, March 1956.
A very brief description of the refraction method of seismic surveying and a short discussion of its revival in the expanding world search for new petroleum deposits.

212. *Seismic Studies of Bikini Atoll.*
M. B. Dobrin & B. Perkins, Jr., U. S. Geol. Surv. Prof. Paper 260-J, pp. 487-505, 1954.

213. *Seismic Reflection Survey at Roma, Queensland.*
J. C. Dooley, Australian Bur. Min. Res., Geol. & Geophys. Rept., No. 16, 1954.

214. *The Subsurface Structure of Western Mecklenburg According to the Results of Seismic Reflection Measurements.* (In German).
R. Meinhold, Geologie, Vol. 4, No. 1, pp. 55-64, 1955.

215. *Some Examples of Geological Results Obtained from Recent Reflection Seismic Surveys in Germany.*
T. Krey, Wendt & K. Roepke, Internat. Geol. Cong, Algiers, 19th Sess., Comptes Rendus, Fasc. 9, pp. 246-266, 1954.

216. *Seismic Study of the Petitjean Jurassic Basin.*
C. Aynard & Vallet, Internat Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 9, Fasc. 9, pp. 285-295, 1954.

217. *Seismic Refraction Studies of Bikini and Kwajalein Atolls and Sylvania Guyot,* 1950.
R. W. Raitt, U. S. Geol. Surv. Prof. Paper 260-K, pp. 507-527, 1954.

218. *Seismic Refraction Profiles in the Submerged Coastal Plain near Ambrose Lightship.*
R. O. Carlson & M. V. Brown, Geol. Soc. Am. Bull., Vol. 66, No. 8, pp. 969-976, 1955.

219. *Seismic Surveying in a Coal Mining Problem.*
J. W. Cruickshank & A. A. Fitch, Colliery Eng., Vol. 31, No. 361, pp. 99-102, 1954.

220. *Explosions in Stone Quarries for Exploration of the Deep Underground.* (Principles, Present Results and Future Possibilities in Germany). (In German).
H. Reinhardt, Frieberger Forschungshefte, C15, Geophysik, pp. 1-91, 1954.

SEISMIC — INSTRUMENTAL

221. *Horizontal Torsion Seismometer.* (In Hungarian).
L. Stegena & I. Jaranyi, Magyar Allami Eötvös Lorand Geofiz. Intezet Geofiz. Kozlemenyek, Kotet 4, Szam 1, pp. 63-66, 1955.

The torsion seismometer described can be changed easily to a horizontal seismometer if the need arises, without practical effect on the constant. The same instrument can thus be used to register all three components.

222. *Shaking Table for Testing Seismometers.* (in Russian).
I. I. Gurvich, Prikladnaya Geofiz., Vypusk 11, pp. 142-151, 1954.

223. *Pressure Gauge for Seismic Investigation Purposes.* (In Hungarian).
J. Galfi & I. Liptay, Magyar Allami Eötvös Lorand Geofiz. Intezet Geofiz. Kozlemenyek, Kotet 3, Szam 10, pp. 143-156, 1954.

A device for measuring pressure waves from subsurface or surface explosions consists of an elastic plate, the deformations of which are transferred into electric signals. These signals can be registered on an oscillograph by means of an indicator based on inductance changes, so that the signal movement measured is directly proportional to the effective pressure. Operation of the device is illustrated by two examples, of air shooting and shothole fatigue.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

224. *A Reflex Galvanometer of Small Dimensions and High Sensitivity.* (In Russian).
G. V. Groshevoy, Akad. Nauk SSSR Geofiz. Inst. Trudy No. 29 (156), pp. 73-75, 1955.

A galvanometer of very small dimensions, with a sensitivity of 8.8×10^{-9} amps/mm.

225. *Prescribed Function Vibration Generator.*
P. M. Honnel, J. Brit. Inst. Radio Engrs., Vol. 16, No. 4, pp. 187-198, April, 1956.

An e.m. system which produces vertical vibrations in the image of prescribed functional waveforms is described and the mathematical theory of its operation derived. The advantage and usefulness of this device for theoretical researches and for routine testing, as compared to the common vibration generator producing sinusoidal motions, is indicated by actual examples of the response of vibration pickups to complex motions of prescribed wave forms.

(Author's Abstract).

226. *Seismographs.*
H. Benioff, Eng. & Arch. Sphere, Vol. 1, No. 3, pp. 9-11, 1953.

Seismic instruments are described briefly, in particular those at the California Institute of Technology stations.

227. *Some Questions of Instrumental Seismology.* (In Russian).
D. P. Kirnos, Akad. Nauk S.S.S.R. Geofiz. Inst. Trudy, No. 27, (154), pp. 1-169, 1955.

This is a treatise on seismic instruments, principally seismographs. A detailed analysis of the operation of the instrument is given, with special attention to the effect of galvanometric recording on the vibrations of the main system. Seismographs adapted to universal use are discussed, as well as special instruments for the measurement and recording of violent earthquakes. A detailed description is given of two typical instruments designed and manufactured in the U.S.S.R. as standard equipment for seismic stations.

(From Geophys. Abstracts 162, U.S. Geol. Survey).

228. *A New Mechanical Low-Pass Filter for Seismogram Analyses.*
T. Akima, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 30, Pt. 1, pp. 53-58, 1952.

Design, construction and operation of a pendulum with electromagnetic damper that can be used to filter seismograms are given.

(From Geophys. Abstracts 162 ,U.S. Geol. Survey).

229. *Transducer Characteristics.*
H. G. M. Spratt, Elec. & Radio Eng., Vol. 34, No. 1, pp. 2-8, January 1957.

The principles of transducers employed for the measurement of the vibration of and strain in mechanical bodies are explained and some representative types are described. The quantity measured is displacement, velocity or acceleration, but any required one is obtainable by subsequent integration or differentiation.

230. *Measurement by Electromechanical Transducers.* (In German).
H. G. Diestel, Acustica, Vol. 6, No. 4, pp. 357-360, 1956.

An apparatus for the continual registration of the frequency curves of electromechanical transducers is described, wherein the commonly found back-coupling onto the driving system is compensated by a control circuit. As examples, the frequency curves of a piezoelectric and an electrodynamic detector for vibrations of solids are given. In a gyratory "one-way system" the relevance of the reciprocity principle is experimentally exemplified.

231. *Eight-Channel Recording on $\frac{1}{4}''$ Magnetic Tape with a Stationary-Tape Playback.*
J. C. Barton, J. Sci. Instr., Vol. 33, No. 11, pp. 415-419, November 1956.

A method of constructing multi-channel magnetic heads is described and their performance reported. The problem of interference between channels is discussed and details given of a new technique for reducing this interference. The playback equipment consists of an eight-channel head mounted on an electrically maintained tuning fork so that it picks up signals from a stationary tape. Signals from each channel are switched electrically in time succession and, after amplification, displayed simultaneously on an oscilloscope. It is possible to resolve pulses recorded along the tape at a separation of 0.1 mm. Precautions necessary for observing very small signals are discussed.

232. *Design Principles for Seismic Reflection Amplifiers.*
A. J. Hermont, Geophysical Prospecting, Vol. 4, No. 3, pp. 279-293, Sept. 1956.

The modern trends to be found in the electrical design of up-to-date seismic amplifier equipment are reviewed. The over-all elementary channel is discussed briefly and the various components are described functionally.

Filtering is mentioned from a point of view of minimum requirements for an average reflection survey, and absolute sensitivity, minimum useful signal voltage from a geophone, and noise are discussed.

Gain control is treated in two regions—automatic and initial. For the former static & dynamic control characteristics are discussed, and the factors influencing the control range are brought out. For the latter, it is pointed out when a system is said to require obligatory or optional initial suppression.

Harmonic distortion, originating in the inductive components of the input circuit due to low-frequency roller energy, is presented in a manner facilitating understanding of the distribution of low-frequency filtering along the channel.

SEISMIC — FIELD TECHNIQUE

233. *Patents.* Abstracts in Geophysics, Vol. 20, No. 4, p. 947, October 1955.

U.S. 2, 706, 011.	12 April 1955.	Seismic air shooting technique with the shots placed at increasing elevations toward the detectors.

234. *Patents.* Abstracts in Geophysics, Vol. 21, No. 2, p. 486, April, 1956.

U.S. 2, 720, 933.	18 Oct. 1955.	Seismic shothole arrangement and time sequence shooting technique to obtain maximum reflection energy from horizon of a particular attitude.
U.S. 2, 721, 617.	25 Oct. 1955.	Seismic shothole arrangement and shooting technique providing a strong point source.
U.S. 2, 724, 452.	22 Nov. 1955.	Air shooting technique with shaped charges.
U.S. 2, 724, 453.	22 Nov. 1955.	Shooting technique which differentiates between reflections and diffractions.
U.S. 2, 728, 405.	27 Dec. 1955.	A continuous-wave seismic testing system using an e.m. source of varying frequency and a spaced detector.

235. *Patents.* Abstracts in Geophysics, Vol. 21, No. 3, p. 856, July 1956.

U.S. 2, 730, 187.	10 Jan. 1956.	A seismic pattern-shooting method.
U.S. 2, 732, 906.	31 Jan. 1956.	A seismic shooting technique.
U.S. 2, 735, 503.	21 Feb. 1956.	A method of preparing a shot hole in unconsolidated material.

236. *Determination of Seismic Wave Velocities in Near-Surface Layers.* (In Hungarian with English & Russian Summaries).
K. Pozgay & E. Janos, Magyar Allami Eötvös Lorand Geofiz. Intezet Geofiz., Kozlemenyek, Kotet 3, Szam 7, pp. 99-105, 1954.

A procedure for determining velocity in near-surface layers with a seismic field instrument, using four closely spaced boreholes.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

SEISMIC — INTERPRETATION

237. *Mean Error of Seismic Reflection Measurements in the Case of Intensely Jointed Fault Structures.* (In Hungarian with English and Russian Summaries).
K. Posgay, Magyar Allami Eötvös Lorand Geofiz. Intezet Geofiz., Kozlemenyek, Kotet 4, Szam 1, pp. 15-23, 1955.

A discussion of rapid methods of approximation suitable for determination of the mean error of arrival time, mean velocity, and mean horizontal co-ordinate of the image point in seismic reflection investigations of strongly jointed fault structures.

238. *Diagramming of a Single Reflection Element by Means of Arcs.* (In German).
L. Krouskij, Erdöl u Kohle, Vol. 8, No. 5, pp. 293, 1955.

A modification of a common trigonometric method of determining depth to a reflecting horizon, applicable to the case of a single reflecting layer. The method is based on the calculation of radii of circles tangent to the layer at the end points of the spread as well as at shot point.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

239. *The Perpendicular-Time Curve in Seismic Reflection.* (In German).
W. Brauch, Erdöl u Kohle, Vol. 8, No. 4, pp. 231-234, 1955.

This paper gives several examples of the mathematical relation between the shape of the perpendicular-time curve and the curve of intersections between the boundary layer and plane of the profile. Determination of velocity from the perpendcular-time curve is shown to be possible under favourable geologic conditions.

240. *The Continuous Velocity Log in Canada.*
E. R. Denton, Canadian Oil & Gas Industries, Vol. 8, No. 12, pp. 43-45, 1955.

The continuous velocity log has been used for obtaining interval velocity data to assist in interpretation of seismic reflection surveys.

241. *Magnetic Record Sections and their Interpretations.*
G. N. Conklin, Paper read at the 1st joint meeting of the Permian Basin Geophys. Soc. and W. Texas Geol. Soc., May, 1956. (Not yet published).

In an effort to present seismic data in such a manner that it can be understood more readily by others than seismologists, Sun Oil Co. has adopted the record section made up of magnetic records. These records usually are corrected for weathering, elevation and moveout and are mixed to enhance the appearance of the reflections. Sections are printed on paper for display purposes and sometimes continuity or lack of it is shown by colours.

Record sections for display include Oklahoma, South Texas, Louisiana and Montana—each selected because a different problem is presented.

242. *The Determination of Mean Velocity by Reflection Travel Times.* (In Japanese with English Summary).
S. Kurihara, Butsuri-Tanko (Geophys. Expl.), Vol. 7, No. 3, pp. 107-120, 1954.

A method of calculating mean velocity from surface to reflector directly from reflection data instead of assuming $v = v_0 + ah$.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

243. *A Theoretical Approach to the Calculation of Seismic Wave Velocity in Sedimentare Formations.*
N. R. Paterson, Royal Soc. Canada Trans., 3rd Ser., Vol. 48, Sec. 4, pp. 59-64, 1954.

Development of interest in seismic wave velocities as a tool for studying the nature of the earth's crust and the development of a theoretical model of structure close to that of sedimentary rocks to determine elastic constants for anisotropic media in order to test the conclusions of the classical wave theory are reviewed. The present work is concerned with testing the theory for different packings of glass spheres in the laboratory. Results indicate that for entire geological sections velocity seems to increase as the one-sixth power of the depth and the one-sixth power of another parameter involving chiefly porosity and cementation.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

244. *The Technical-Economic Aspects of Automatic Data Reduction.*
R. W. Olson, Geophys. Prospecting, Vol. 4, No. 4, pp. 335-347, Dec. 1956.

The background of automatic data processing as well as other improvements in prospecting methods is almost certainly economic. Automatic processing can contribute to the increasing utility of seismic data. Time is saved and at the same time a greater volume of work is provided.

It is expected, however, that the ultimate and greatest value will be better interpretation.

Time concepts in the processing of seismic data are vital either in simple time connections of either static or dynamic nature or in treatment of signals in the time domain.

Much development work is needed before these advantages can be realised. Principal development needed is an increase in dynamic range in the overall system.

245. *Computation of Wavefront Velocity in a Uniaxial Inhomogeneous Body of Seismic Refraction Measurements.* (In German).
M. Weber, Geofis. Pura e Appil., Vol. 34, No. 2, pp. 1-20, May-Aug. 1956.

The theory of the interpretation of seismic travel-time surfaces for refracted rays in parallel structures is treated in a new manner, under the assumption that the depth-velocity function of any bed can be expanded in a power series.

SEISMIC — THEORY & RESEARCH

246. *Fourier Transform Method for the Treatment of the Problem of the Reflection of Radiation from Irregular Surfaces.*
W. C. Meecham, J. Acoust. Soc. Am., Vol. 28, No. 3, pp. 370-377, May, 1956.

A Fourier transform method is presented which can be used for the calculation of the distribution of energy reflected from irregular surfaces. The formulation is useful for the first boundary value problem and can be used in either two-or three-dimensional problems with any given incident field. This method is found to be better than former physical optics methods (such as Rayleigh's), since the error in the transform method is of second order in the surface slope whereas the error in previous methods is of first order in the same quantity.

247. *Some Problems of Shallow Refraction Investigations.*
W. Domzalski, Geophysical Prospecting, Vol. 4, No. 2, pp. 140-166, June 1956.

The term shallow refraction, as used in this paper, refers to investigations confined to the superficial layer of rocks, composed primarily of unconsolidated material. To define the scope of the discussion it will be assumed that the term shallow refraction applies to work of which the lower limit is approximately 300 feet and the upper of the order of a few feet. The consideration of the small magnitude of quantities measured (distances and times) determines the perspective of the problems involved, since difficulties encountered in the interpretation, although equally disturbing whether in deep or shallow work, will cause a greater percentage of error in the latter case. The purpose of this paper is to discuss and illustrate these problems.

The factors considered include the location of the geophone spread in relation to the topography of the site, influence of the ground conditions in the vicinity of geophones on recorded times, consideration of the shallow uphole shots and problems arising from the repeated use of the same shothole. The rapid variation in the vertical velocity of the overburden and errors due to it are discussed together with the effects of a non-homogeneous unconsolidated material and velocity reversal. The effects of the ill-defined solid rock surface are also considered. It appears that as the depth of investigations becomes shallower, the limits of the practical capabilities of the method are approached, because the differences between the theoretical assumptions and the actual conditions become more pronounced.

(Author's Abstract).

248. *Seismic Efficiency of Explosives.*

H. Richard & M. Pieuchot, Geophysical Exploration, Vol. 4, No. 2, pp. 167-184, June 1956.

The parameters which characterise an explosive are derived from laboratory tests and none is directly usable for seismic purposes. Another one, derived from field experiments, is proposed in this paper. It allows the comparison of two different explosives. The test must be conducted with care. Precautions concerning the equipment and the shot point are detailed. The first available results suggest that the new parameter does not depend on the size of the charge nor on the shooting conditions, though the experimental data are not numerous to allow a general statement. It is shown how a coefficient of seismic efficiency can be used for selecting an explosive; and considerable amounts of money can be saved by the best choice. More studies on the generation of artificial seismic waves would be highly profitable.

(Author's Abstract).

249. *The Relation between Size of Charge and Amplitude of Refracted Wave.*

T. F. Gaskell, Geophysical Prospecting, Vol. 4, No. 2, pp. 185-193, June 1956.

Experiments carried out using charges of up to 200 lbs. at a distance of about 20,000 ft. from the geophones suggest that the amplitude of the refracted wave ground motion is roughly proportional to the weight of charge. Simple energy considerations lead one to expect a relation of a form in which velocity amplitude is proportional to $\sqrt{W}$.

An explanation of the observed relation may be based on a theory according to which the efficiency of the explosion increases with the source size, that is the distance from the source at which the pressure wave of the explosion ceases to cause permanent deformation of the surrounding medium.

The above theory was further confirmed by measurements of the radius of the cavity produced by explosions of charges of different size in clay. Also, explosions of charges in artificial water-filled cavities were found to give seismic wave amplitudes three or four times greater than those produced by the same charge in a narrow hole. It is possible that these observations explain in part why the charges required in marine refraction experiments are very much smaller than those needed in refraction work on land, but additional reasons for this difference are also discussed.

(Author's Abstract).

250. *Geometrical Acoustics. I. The Theory of Weak Shock Waves.*

J. B. Keller, J. Appl. Phys. Vol. 25, No. 8, pp. 938-947, August 1954.

The mathematical foundations of geometrical acoustics (the application of geometrical optics to acoustic waves) is provided. Discontinuity conditions in arbitrary continuous media are derived and it is shown that shocks, contact discontinuities, and phase-change fronts are the only possible types of discontinuity. The acoustic equations and discontinuity conditions are obtained and the application of geometrical optics to the motion of the shock front is demonstrated. An expression is obtained for variation of shock strength along rays. Applications of the method to reflection and transmission at a contact discontinuity and to the shock tube are shown.

251. *Geometrical Acoustics.* II. *Diffraction, Reflection and Refraction of a Weak Spherical or Cylindrical Shock at a Plane Interface.*
F. O. Friedrichs & J. B. Keller, J. Appl. Phys., Vol. 26, No. 8, pp. 961-966, August 1955.
The method described in part I is applied to the reflection and refraction of a spherical or cylindrical acoustic pulse at a plane interface between two media and at a plane slab separating two media. The discontinuity across the diffracted shock wave, which appears in the lower-velocity medium when the disturbance orginates in it, is investigated.

252. *Seismic Model Experiments.*
H. E. Tatel, Trans. Am. Geophys. Un., Vol. 37, No. 3, p. 360, June 1956.
(Abstract only of paper read at the 37th Annual Meeting of the Am. Geophys. Un., Washington, April-May 1956 — Not yet published).
Three-dimensional model experiments have been continued. Using surface transmitters and receivers, multiple seismograms of homogeneous (iron) models with surface irregularities have been studied. The patterns obtained simulate those found in field work, and indicate that the conversion process of compression to Rayleigh waves and the converse play a dominant role in the formation of a field seismogram.

253. *On the Apparent Modulus of Elasticity of Porous Solids.* (In Italian).
I. Barducci, La Ricerca Sci., Vol. 24, No. 3, pp. 528-533, 1954.
Gatto's method of studying the influence of isolated holes on the velocity of sound in metals has been extended to a theoretical examination of the effect of a great number of statistically distributed small cavities on the Young's modulus of a solid. It is demonstrated that, in contrast to Gatto's case, the effect of porosity is the same for both static and dynamic measurements; it consists of a decrease of apparent modulus in proportion to a decrease in density. These results agree very well with recent experiments on fritted materials by Berducci and Cabarat.
(From Geophysical Abstracts 164, U.S. Geol. Survey).

254. *The Results of Laboratory Determinations of the Elastic Properties of Rocks.* (In Russian).
M. L. Ozerskaya, Prikladnaya Geofiz., Vol. 12, pp. 93-106, 1955.
Seismic velocities, usually determined by seismic well logging, may be measured in the laboratory on core samples from drill holes, either by seismoacoustic measurements or by observing the height of elastic rebound from the surface of the core specimens with a scleroscope, an instrument currently used in technology for the determination of hardness. The procedure is very simple and gives results not less reliable than those obtained by the ultrasonic impulse method. Discrepancies between the results obtained by these two methods and those of seismic well logging are not attributable to the new method. Comparison of data on porosity, density, seismic velocity and the height of rebound indicates a simple linear correlation among them.
(From Geophysical Abstracts 164, U.S. Geol. Survey).

255. *Stress Waves in Solids.*
R. M. Davies, Brit. J. Appl. Physics, Vol. 7, No. 6, pp. 203-209, June 1956.
An elementary discussion on the topic of the transmission of transient stress pulses of short duration in solids, together with the associated problem of the

measurement of pressures subject to very rapid changes. The pressure bar method, devised by Bertram Hopkinson, forms one of the basic experiments in the field and it is described in some detail. An analysis of the limitations of the method leads to a discussion of the change of form of stress wave pulses as they recede from the origin, and the main features of the distortion are discussed when the pulses are propagated in (a) elastic solids, (b) visco-elastic solids, and (c) solids stressed beyond the elastic limit.

(Author's Abstract).

256. *On A. M. Yepinat'yeva's Paper "Secondary Pressure-Bubble Pulses in Seismic Exploration."* (In Russian).
A. I. Slutskovski, Prikladnaya Geofiz., Vypusk 10, pp. 109-113, 1953.

Frequency spectra of explosions obtained with a 24-channel receiver show that Yepinat'yeva's assumptions were wrong, when he said that the duration of the first explosion is always shorter than that of the secondary pulses and that the pressure produced by this explosion grows exponentially.

257. *The Scattering of Surface Wave Motions by Topographic Irregularities.*
L. Knopoff & A. F. Gangi, Trans. Am. Geophys. Un., Vol. 37, No. 3, p. 351, June 1956. (Abstract only of paper read at the 37th Annual Meeting of the Am. Geophys. Un., Washington, April-May 1956 — Not yet published).

A three-dimensional seismic model of Lamb's problem with an irregular boundary has been used to study the scattering by topography of wave motion in the surface. The scattering may be interpreted in terms of the interactions *P-P*, *R-R*, *P-R* and *R-P*. The last two of these are considered to cause much of the seismic noise; the *P-P* and *R-R* interactions are studied here in detail.

258. *S-Waves at a Solid-Liquid Interface.* Part 1. (In German).
T. Matuzawa, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 32, Pt. 1, pp. 1-5, 1954.

The behaviour of SH-waves at the boundary between viscous and solid bodies is developed mathematically. There seems a possible use for S-waves in the detection of phase changes in the earth's crust.

259. *S-Waves at a Solid-Liquid Interface.* Part 2. (In German).
T. Matuzawa, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 32, Pt. 2, pp. 155-160, 1954.

The behaviour of SV-waves at the boundary between viscous and solid bodies is developed mathematically.

260. *Interfacial Waves in Viscoelastic Media.*
C. M. Tchen, J. Appl. Phys., Vol. 27, No. 5, pp. 431-434, May 1956.

The stability of waves on the interface of two superposed semi-infinite layers of incompressible media is studied. The two uniform layers are of different densities and different viscoelastic properties. Gravity, Taylor acceleration and surface tension are taken into consideration. The main problems considered are the dispersion, decay and growth of waves, and the formulation of a hydrodynamical foundation for the cohesive action of elasticity.

(Author's Abstract).

261. *Diffraction of Waves from an Irregular Surface. I. General Theory; Applications of the Theory.*
L. M. Brekhovskikh, Zh. Eksp. Teor. Fiz. 23, Vol. 3, No.9, pp. 275-314, 1952.

The problem of determining the diffraction of sound and e.m. waves from irregular surfaces is very difficult and, so far, an exact solution has not been found. The first attempt was made by Rayleigh, who found an approximate solution for a sinusoidal surface with small amplitudes. Here is presented an approximate method of solution for surfaces having radius of curvature at all points sufficiently large in comparison with the wavelength, whereby the character of the irregularity and the physical properties of the medium bounded by the irregular surface can be arbitrary.

262. *Seismic Waves from a Transducer at the Surface of Stratified Ground.*
F. F. Evision, Geophysics, Vol. 21, No. 4, pp. 939-959, Oct. 1956.

Vibration impulses of variable frequency and duration have been generated by means of an electrically excited vibrator and the resulting seismic waves recorded at the ground surface along a 200 ft. traverse. The first arrivals were refractions from the water table and a deeper claysiltstone interface, and these checked with the results of a standard refraction survey. The amplitudes of displacement of the refracted waves varied in each case with approximately the inverse square of distance, the critical distance was marked by a discontinuity of amplitude. Two later impulsive arrivals recorded within 50 msec. of the first were interpreted respectively as a transformed reflection from 85 ft. depth and an ordinary compressional reflection from 200 ft. depth. A dispersive Rayleigh wave gave an independent estimate of the shear velocity and thickness of the surface layer. Aircoupled waves of frequencies 70.8 c.p.s. and 330 c.p.s. were recorded and have been related to the first- and third-mode Rayleigh wave respectively.

263. *Piezoelectric Transducers.*
A. C. Dobelli, Acustica, Vol. 6, No. 4, pp. 346-356, 1956.

A brief review is presented of the properties and parameters of the most widely used piezoelectric materials some of which are given in terms of equivalent circuits; next some of the considerations that should be given to the choice of materials and dimensioning of the element for particular applications. A few piezoelectric crystals are characterized which, although not used on a commercial scale, are nevertheless of scientific interest. In conclusion, some references are given to some recent developments in the field of piezoelectric polycrystalline ceramics.

264. *Backscattering of Sound from the Sea Surface: its Measurement, Causes, and Application to the Prediction of Reverberation Levels.*
R. J. Urick & R. M. Hoover, J. Acoust. Soc. Am., Vol. 28, No. 6, pp. 1038-1042, Nov. 1956.

Using two transducers—one for transmitting, one for receiving—mounted so as to be rotatable in a vertical plane and suspended from a buoy, measurements have been made of the backscattering of sound pulses from the surface of the sea as a function of grazing angle between 5 and 90 degrees, wind speed between 3 and 18 knots, and pulse length. When converted to a scattering coefficient per unit area, the results provide some hints as to the processes by which sound is scattered by the ocean surface and give the basic data for computing the reverberation to be expected with transducers of arbitrary beam width and orientation.

265. *Velocity of Lg Waves in California.*
F. Press, Trans. Am. Geophys. Un., Vol. 37, No. 5, pp. 615-618, Oct. 1956.

It is of interest to establish whether or not the crust is anomalous in organic belts. The velocity of Lg waves for paths traversing orogenic belts in California differs by less than 2% from velocities found for transcontinental paths. These results suggest that the velocity of shear waves in the upper part of the continental crust is uniform, but do not necessarily imply homogeneity of materials that make up the crust.

266. *Characteristics of Explosives for Marine Seismic Exploration.*
J. J. Jakosky & J. Jakosky, Jnr., Geophysics, Vol. 21, No. 4, pp. 969-991, Oct. 1956.

The results of preliminary studies and large-scale field tests in California are described. These studies are part of an investigation to develop an explosive which would overcome some of the disadvantages of black powder, which now is the only explosive permissible for offshore exploration in California.

Special instrumentation was developed for recording the pressure-time curves from underwater explosions.

The predominant characteristics of these curves have been related to seismic record quality and the destruction of fish and other marine life. The experimental studies have shown that non-lethal explosives are available which will give record quality and operating costs comparable to the conventional dynamites and which are superior to the black powders.

267. *Theoretical Questions on Multiple Geophones for Underground Measurements.* (In German).
A. Celmins, Geophys. Prosp., Vol. 4, No. 4, pp. 365-393, Dec. 1956.

The arrays of multiple geophones used in underground seismic prospecting must satisfy two conditions:

(1) In each group only a few geophones can be used.
(2) The array must work in a rather wide frequency band.

In this paper the effect of the 3 parameters (geophone spacing, sensitivity and time shift) of a linear array is investigated in order to improve the directional sensitivity of the array.

Necessary conditions which are independent of the frequencies are found for the optimum sensitivities of the geophones in a linear array.

The optimum values of the parameters mentioned above are calculated for arrays of 2 and 3 geophones and for a frequency band width which may be used in underground seismic prospecting.

268. *Scale Model Seismic Experiments.*
S. H. Hall, Geophys. Prosp., Vol. 4, No. 4, pp. 348-364, Dec. 1956.

An experimental arrangement is described using an electric spark as source and barium titanate as a detector. Model experiments were made in water with the source mounted above the surface. The effect on the pulse shape on transmission through the air-water interface and the change of pulse shape with depth were investigated. A number of profiles are presented of reflections from a slate slab immersed in the water with different arrangements of the model and detector.

269. *Investigation of Shear Waves.*
R. N. Jolly, Geophysics, Vol. 21, No. 4, pp. 905-938, Oct. 1956.

A series of measurements was made to investigate some of the fundamental properties of shear waves and to explore the possibility of using horizontally polarized (SH) shear waves for reflection prospecting. A special source was devised to produce a shearing motion which was detectable as far as 400 feet vertically and 1,000 feet horizontally. Direct, refracted and reflected *SH* and *SV* (vertically polarized) shear waves were identified on a series of surface and subsurface recordings. A strong, highly dispersive surface wave, which satisfies the theoretical criteria of Love waves, was also observed.

Certain anomalous features of the data which did not conform to the predictions of simple isotropic theory were readily explained by considering the stratified section under observation to be transversely isotropic. It was found that horizontal *SH* velocity exceeded vertical *SH* velocity by 100% whereas the corresponding compressional wave velocities differed by only 12%. *SV* anisotropy was manifested by a complex variation of velocity at intermediate directions of travel. Other theoretical predictions were confirmed in detail by the experimental data.

An evaluation of *SH* reflection recording was made in four different areas. It was possible at one location, using multiple horizontal geophones and the shear source, to obtain an *SH* reflection from the base of a thick weathered layer. However, the results in general indicate that the method is not likely to have much practical importance.

270. *The Seismic Pulse in Materials Possessing Solid Friction,* I: *Plane Waves.*
L. Knopoff, Bull. Seismol. Soc. Am., Vol. 46, No. 3, pp. 175-183, July 1956.

With references to work, by Jeffreys and Ricker, on the propagation of seismic pulses through viscoelastic media, the author presents his own results of a mathematical study of wave motions close to the source of motion.

271. *Phase Change of PP and pP on Reflection at a Free Surface.*
R. E. Ingram, et al, Bull. Seismol. Soc. Am., Vol. 46, No. 3, pp. 203-213, July 1956.

The question of phase change on reflection at a free surface is investigated for all values of Poisson's ratio σ. It is shown once again that for $\sigma > 0.2631$ there is always a phase change on reflection. For $\sigma < 0.2631$ there are certain angles of incidence for which there is no phase change on reflection. These angles are determined for values of σ between 0.26 and 0.00. The results are also expressed, for various focal depths, in terms of the epicentral distances for *PP* and for *pP* between which there has been no phase change on reflection.

272. *The Oblique Reflexion of Sound Pulses.*
J. W. Craggs, Proc. Roy. Soc., Vol. 237, No. 1210, pp. 372-382, 6th Nov. 1956.

It is observed that the classical theory of reflexion of plane sound waves breaks down in the use in which a sound pulse is incident on a plane surface of separation of two media at an angle such that total reflexion is to be expected. A sound wave is imagined to be generated by the supersonic motion of a thin wedge, and the motion when the wave meets the surface of separation is investigated by assuming dynamic similarity in the motion. It is shown that the solution of the problem is not of quasi-steady type, and that there is a diffused wave in the denser medium, with a wave front which precedes the incident wave near the surface of separation. This wave is due to diffraction in the lighter medium round the edge of the incident wave. A further result is that there is still a reflected wave, and that its amplitude is equal in magnitude but opposite in sign to that of the incident pulse.

273. *Multiple Reflections in Northwest Germany.*
R. Bortfeld, Geophys. Prosp., Vol. 4, No. 4, pp. 394-423, Dec. 1956.

In N. W. Germany multiple reflections have been observed in numerous areas. They are not curiosities but represent true problems.

Most of the multiples are of the type *AB* (a multiple caused by reflections at two different reflectors *A* and *B*, and at the surface). It is also shown (by a rough estimate) that this type of multiple is theoretically the most probable. Finally, the interference between the two components of *AB* (one multiple being reflected first at *A*, then at *B*, and the other reflected first at *B*, then at *A*), and its appearance in constructed examples, are discussed.

GRAVITY — GENERAL

274. *Gravity Investigation in the Renovo Area of Central Pennsylvania.*
S. Jarmell, Producers Monthly, Vol. 20, No. 5, pp. 36-40, March 1956.

275. *Prospecting for Chromite with Gravimeter and Magnetometer over Rugged Topography in East Turkey.*
S. Yüngül, Geophysics, Vol. 21, No. 2, pp. 433-454, April 1956.

276. *Gravity Measurements in Alaska and the Yukon Territory.*
H. E. Tatel, Trans. Am. Geophys. Un., Vol. 37, No. 3, p. 359, June 1956.
(Abstract only of paper read at the 37th Annual Meeting of the Am. Geophys. Un., Washington, April-May 1956 — Not yet published).

277. *Standardization of the World's Gravity Data.*
G. P. Woolard, Trans. Am. Geophys. Un., Vol. 37, No. 3, p. 363, 1956.
(Abstract only of paper read at the 37th Annual Meeting of the Am. Geophys. Un., Washington, April-May 1956 — Not yet published).

Investigations of the relative accuracy of the world's gravity data show substantial errors in some of the national gravity bases and also the lack of a common reference standard. The need for observations accurate to two milligals and preferably one milligal has led to an international programme for the establishment of an acceptable standard which will be discussed along with the applicability of gravity data to geophysical, geologic and geodetic problems.

278. *Gravity Surveys to Determine Possible Fault Trends.*
L. S. Morrison, Mines Mag., Vol. 45, No. 10, pp. 112-114, 1955.

A discussion of the appearance of the gravity expression of a typical fault superimposed on a typical regional gravity anomaly with various orientations and with comparable examples from field gravity surveys.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

279. *Regional Gravity Survey of the Moorlands Military Sheet Area.*
K. R. Seedsman, South Australia Dept. Mines Min. Rev., No. 98, pp. 158-161, 1953 (1955).

280. *The Geological Results of Measurements of Gravity in East Carmarthenshire.*
J. T. Whetton, J. O. Myers & I. J. Watson, Geofis. Pura e Appl., Vol. 32, pp. 43-53, 1955.

281. *Gravity and Magnetic Anomalies in North Wales; with an Appendix on the Magnetic Anomalies over the Lleyn Peninsula.*
D. W. Powell, D. H. Griffiths & R. F. King, Geol. Soc. London Q. J., Vol. III, Pt. 4, pp. 375-397, 1955 (1956).

282. *Gravity and Techtonics in the Marche and in Eastern Abruzzi.* (In Italian).
C. Morelli, Ann. Geofis., Vol. 8, No. 4, pp. 475-513, 1955.

283. *On Some Correlations between the Geologic and Gravimetric Surveys in the Marche, Umbria and Abruzzi.* (In Italian).
F. Scarsella, Ann. Geofis., Vol. 8, No. 4, pp. 515-519, 1955.

284. *Increase in the Density of Gravimetric Observations in the East Central Zone of the Alpine Arc.* (In Italian).
A. Norinelli, Ann. Geofis., Vol. 8, No. 4, pp. 401-416, 1955.

285. *Gravity Survey in Japan 1. Gravity Survey in Hokkaido District.*
Geographical Survey Institute, Geog. Survey Inst. Japan Bull., Vol. 4, Pt. 2, pp. 23-99, 1955.

286. *Study of Gravity in Madagascar.*
L. Cattala, Inst. Sci. Madagascar Mem., Ser. D, Tome 6, pp. 1-33, 1954.

287. *The Nature of the Gravity Anomalies in the Saratov Region of the Volga Basin.* (In Russian).
O. A. Shvank, Prikladnaya Geofiz., Vypusk 12, pp. 66-92, 1955.

288. *An Interpretation of the Gravity Anomalies in the Eastern Mediterranean.*
J. C. Harrison, R. I. B. Cooper & R. W. Hey, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 9, fasc. 9, pp. 39-42, 1954.

289. *Gravimetric Survey of Tuscany* 1953. *Faye and Bouguer Anomalies.* (In Italian).
G. Salvioni, Boll. Geod. e Sci. aff., Vol. 13, No. 4, pp. 299-360, 1954.

290. *Gravimetric Survey of the Island of Capri and the Sorrento Peninsula.* (In Italian).
A. Maino, Serv. Geol. Italia Boll., Vol. 76, No. 1, pp. 325-342, 1954.

291. *Standardization of the World's Gravity Data.*
G. P. Woolard, Trans. A. G. U., Vol. 37, No. 6, pp. 669-675, Dec. 1956.

The problems of gravity standardization are discussed from the standpoint of absolute determinations, relative measurements of gravity on a world wide scale for calibration and reference purposes and internal national networks. Work is in progress to improve present standards; in particular, the pendulum programme that has been carried out under the auspices of the Air Force Cambridge Research Centre and which is being extended as part of the International Geophysical Year programme is discussed. The extent of the world programme of gravimeter measurements for evaluating present standards, which has been carried out under the auspices of the Office of Naval Research, and a programme for the development of an internal network of gravity bases at the principal airports in the United States for use in co-ordinating and integrating gravity data taken by various groups in this country are presented.

GRAVITY — INSTRUMENTAL

292. *Patents.* Abstracts in Geophysics, Vol. 21, No. 3, p. 854, July 1956.

U.S. 2, 732, 717.	31 Jan. 1956.	A conical pendulum type of gravimeter.
U.S. 2, 732, 718.	31 Jan. 1956.	A Worden type gravimeter with full temperature compensation.
U.S. 2, 738, 676.	20 Mar. 1956.	A large range Worden type gravimeter.

293. *The Determination of Gravity by the Oscillations of a Free Pendulum.* (In Spanish).
H. de Castro, Petrol. Mexicanos, Vol. 2, No. 6, pp. 428-432, 1955.

Determination of the force of gravity by use of the pendulum is briefly reviewed.

294. *Elementary Theory of Gravimeters Built as Spring Balances.* (In Russian).
K. E. Veselov, Prikladnaya Geofiz., Vol. 12, pp. 127-156, 1955.

About 20 different gravimeters are described. Accuracy, reliability and convenience in field operations are analyzed.

295. *The Atlas Gravimeter, Model F. Description, Calibration and Maintenance of the Instrument.* (In Spanish).
J. Borrego Gonzalez, Rev. Geofis., Vol. 13, No. 51-52, pp. 233-257, 1954.

296. *Concerning the Evaluation of the Drift of Zero Point in Gravimeters.* (In Russian).
P. F. Shokin, Akad. Nauk SSSR Geofiz. Inst. Trudy, No. 29 (156) pp. 98-106, 1955.

The drift of the zero point in gravimeters with a quartz elastic element is pronounced and unavoidable. It is usually assumed that the drift is linear between two calibrations. Shokin investigated the behaviour of seven different gravimeters during 50 trips and concludes that the amount of drift is not linear with time, but is influenced by several factors. This can be seen from the fact that the coefficient of correlation between the amount of drift and time ranged from only 0.38 to 0.67. Conditions of the transportation are certainly important and cannot be neglected.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

GRAVITY — FIELD TECHNIQUE

297. *Gravity Meter Exploration in Marine Areas.*

E. Frowe, Geophysics, Vol. 20, No. 3, p. 716, July 1955.

(Abstract only of paper read at the 10th Annual Gulf Coast meeting of the S.E.G. at San Antonio, Texas, 1955).

This paper described methods of conducting gravity meter surveys in water-covered areas such as bays, lakes and oceans. Types of boats, gravity meters, surveying techniques, cost per station, reliability of results and problems are discussed. Typical gravity meter anomalies encountered in the Gulf of Mexico are shown.

298. *Observations of the Vertical Gradient of Gravity in the Field.*

S. Thyssen-Bornemisza & W. F. Stackler, Geophysics, Vol. 21, No. 3, pp. 771-779, July 1956.

Field observations of the anomalous vertical gravity gradient were made at Houston, Texas and over the Turner Valley structure near Calgary, Alberta, Canada. The results obtained are encouraging, but the precision of the measurements was to some extent reduced by vibrations generated in transporting the gravimeter up and down the tripod, as well as by gusts of wind.

(Author's Abstract).

GRAVITY — INTERPRETATION

299. *The Generalization of a Criterion for the Verification of the Interpretation of Gravitational Observations.* (In Russian).

K. L. Smolitskiy, Akad. Nauk SSSR Doklady, Vol. 106, No. 2, pp. 237-238, 1956.

Lyapunov's criterion for the verification of the interpretation of gravitational observations in the case of an infinite cylindrical mass of arbitrary cross section buried underground is derived in a more general way, making it applicable to bodies of finite dimensions of any form. The mathematical treatment is based on potential theory and is very general, but is also applied to specific geometric shapes resulting in simpler formulae.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

300. *Use of the Second Vertical Derivative of the Potential of Gravity in the Geologic Interpretation of Gravimetric Survey.* (In Russian).

K. E. Veselov, Prikladnaya Geofiz., Vypusk 11, pp. 152-162, 1954.

In gravimetric exploration it is important to be able to separate local from regional anomalies. Conditions can be improved by recalculating the observed gravity data to another, preferably a lower, level nearer the disturbing bodies. Even better is the use of the second vertical derivative of the potential function. These calculations are simple, though time consuming. Examples of the use of this procedure are .given.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

301. *On a Criterion for the Verification of the Interpretation of Gravimetric Observations.* (In Russian).
A. A. Lyapunov, Akad. Nauk SSSR Doklady, Vol. 102, No. 2, pp. 265-266, 1955.

The integrated gravitational intensity of a horizontal infinite cylindrical mass for a profile on the earth's surface is derived. The formula is used as an aid in the interpretation of gravitational anomalies.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

302. *Tidal Gravity Corrections for* 1957.
Ser. Hydrograph de la Marine & Comp. Gen de Geophys. Geophysical Prosp., Vol. 4 (Suppl. No. 1), Dec. 1956.

These tables give hourly corrections to be added to the gravity values shown by the instruments in order to obtain the values as they would be without the disturbing influence of the moon and sun. The factor 1.2, required to take into account the elasticity of the earth, has been incorporated in the values of the tables.

The values are given in hundredths of mgal and rounded off to half a hundredth.

303. *The Use of Integrators Helps Computing Terrain Corrections in Gravimetry.*
C. Monnet, Geophysical Prosp., Vol. 4, No. 3, pp. 236-248, Sept. 1956.

A special method is described for calculating the terrain correction of the observed gravity data. The ground around each station is divided into sectors and a special integral of the topographical section is calculated along each dividing radius.

A computation chart has been constructed, which reduces integration to measurement of its separate sections, or area moments, by means of planimeter or integrator.

This paper shows how to trace the computation chart for the use of the first moment method.

Experience has shown the method affords a more speedy calculation and is superior to other methods of terrain correction.

304. *Bouguer Corrections with Varying Surface Density.*
R. Vajk, Geophysics, Vol. 21, No. 4, pp. 1004-1020, Oct. 1956.

The Bouguer correction is made, as a rule, to sea level and by using an average density value of the rocks, determined by the profile method. However, if the density of the rocks forming the topography varies from place to place, then the proper density value should be used for every topographical feature.

The Bouguer correction with varying density should be made only to a surface drawn through the low points of the topography. Below this surface, and to sea level, a constant density value should be used all over the area; otherwise, non-existing gravity anomalies may be introduced into the results of the survey, or existing gravity anomalies may be distorted.

A few examples are given for computing Bouguer corrections with varying surface density, and to illustrate the errors introduced by using improper density values.

GRAVITY — THEORY & RESEARCH

305. *Tides in the Solid Body.*
A. Lopez Arroyo, Rev. Geofis., Vol. 13, No. 49. pp. 37-76, 1954.

A review of the tides in the solid earth body, including oceanic tides, deviations of the plumb line, displacement of the pole, variation of latitude and the variation of the gravity potential combined with the elasticity of the globe.

306. *Earth Tides.*
P. J. Melchior, Ciel et Terre, Vol. 70, Nos. 1-2, p. 22; pp. 103-131; 5-6, pp. 191-217; 7-8, pp. 266-288 and 11-12, pp. 435-454, 1954.

A very detailed mathematical treatment of the question of earth tides. The five aspects of the phenomenon are:

1. Reduction of the amplitude of oceanic tides;
2. deflections of the vertical with respect to the crust;
3. deflections of the vertical with respect to the axis of the globe;
4. variations in the intensity of gravity, and
5. deformations of the crust.

MAGNETIC — GENERAL

307. *Prospecting for Chromite with Gravimeter and Magnetometer over Rugged Topography in East Turkey.*
S. Yüngül, Geophysics, Vol. 21, No. 2, pp. 433-454, April 1956.

308. *The Remanent Magnetism of Varved Clays from Sweden.*
D. H. Griffiths, Mon. Not. Roy. Astronom. Soc., Geophysical Suppl., Vol. 7, No. 3, pp. 103-114, December 1955.

The directions of remanent magnetization of samples taken from a number of varved clay series from Sweden have been measured in an attempt to obtain information about the direction of the earth's field in past times. Comparison of direction of magnetization of clay samples with observatory records of the earth's field at the time of deposition of the clay indicate that the magnetizations were acquired on deposition and have remained stable since then. Various factors that influenced the direction of magnetization are discussed and possible corrections suggested.

309. *The Remanent Magnetism of Artificially Deposited Sediments.*
R. F. King, Mon. Not. Roy. Astronom. Soc., Geophys. Suppl., Vol. 7, No. 3, pp. 115-134, December 1955.

A description of experiments carried out in an attempt to discover what factors, other than the magnetic field, control the direction of magnetization of particles of sediment, giving the latter its remanent magnetism. Two inportant factors were found to be the slope of the surface on which the sediment was deposited and the velocity of the current immediately above this surface.

310. *An Airborne Magnetic Survey of the West Indies, Gulf of Mexico, and the Eastern United States Continental Margin.*
M. J. Davidson & E. T. Miller, Trans. Am. Geophys. Un., Vol. 37, No. 3, p. 341, June 1956. (Abstract only of paper read at the 37th Annual Meeting of the Am. Geophys. Un., Washington, April-May 1956 — Not yet published).

311. *Gravity and Magnetic Anomalies in North Wales; with an Appendix on the Magnetic Anomalies over the Lleyn Peninsula.*
D. W. Powell, D. H. Griffiths & R. F. King, Geol. Soc. London Q. J., Vol. 111, Part 4, pp. 375-397, 1955 (1956).

312. *Magnetic Observations in the Middleback Range Area.*
D. McPharlin, S. Australia Dept. Mines Min. Rev., No. 98, pp. 140-149, 1953 (1955).

313. *The Geology and Iron Ore Resources of the Middleback Range Area: Appendix 1, Magnetic Observations in the Middleback Range Area.*
D. McPharlin, S. Australia Geol. Survey Bull., No. 33, pp. 199-205, 1954.

314. *Discovery by Magnetic Exploration of a Bed of Iron Ore in the Calymenes Schists South of the Flamanville Granite* (*Manche*). (In French).
P. Bassompierre & F. Munck, Soc. Geol. France Comptes Rendus, No. 3, pp. 32-34, 1955.

315. *The Magnetic Anomalies in the Hohe Venn Mountains.* (In German).
W. Wolff & A. Hahn, Geol. Jahrb., Band 69, pp. 71-82, 1954.

316. *Second Order Magnetic Survey of Japan:*
Geographical Survey Institute, Geog. Survey Inst. Japan Bull., Vol. 4, Part 1, pp. 49-57, 1954.

317. *Ilmenite in Norway.*
Mining Magazine, Vol. 93, No. 6, pp. 361-362, 1955 and Vol. 94, No. 1, pp. 41-42, 1956.
An aeromagnetic survey over 300 square miles in S. W. Norway.

318. *Regional Geomagnetic Field for Sicily.* (In Italian).
G. L. Spinicci, Riv. Geofis. Appl. Vol. 15, No. 2, pp. 105-123, 1954.

319. *Magnetic Survey of the North-Central Portion of Sicily.* (In Italian).
M. Giorgi, E. Medi & F. Molina, Ann. Geofis., Vol. 8, No. 1, pp. 23-58, 1955.

320. *Magnetic Structure of Bikini Atoll.*
L. R. Alldredge, F. Keller & W. J. Dichtel, U.S. Geol. Survey, Prof. Paper 260-L, pp. 529-535, 1954.

321. *On the Magnetic Anomalies and their Secular Variations Around Maeyama on Simabara Peninsula.*
W. Yoda, Kyoto Univ. Coll. Sci. Mem., Ser. A, 1.27, No. 21, pp. 101-123, 1954.

322. *Magnetic Properties of Ferromagnetic Minerals Contained in Igneous Rocks.*
S. Akimoto, Japanese J. Geophys., Vol. 1, No. 2, 1955.

323. *Aeromagnetic Survey in Lac la Ronge District.*
A. J. Budding, Precambrian, Vol. 27, No. 7, pp. 22 & 24, 1954.

324. *A Vertical Force Magnetic Survey of the Counties Roscommon, Longford, Westmeath, and Meath.*
T. Murphy, Dublin Inst. for Advanced Studies, Geophys. Bull. 11, 1955.

325. *Geological and Geomagnetic Study of the Cambrian Massif of Serpont* (*Belgian Ardennes*). (In Italian).
C. Gaibar Puertas & E. L. L. Hoge, Internat. Geol. Cong., Algiers, 19th Sess., Copmtes Rendus, Fasc 9, pp. 131-134, 1954.

MAGNETIC — INSTRUMENTAL

326. *Patents.* Abstracts in Geophysics, Vol. 20. No. 4, p. 947, October 1955.

U.S. 2, 706, 801.	19 April 1955.	A compensating system for an airborne magnetometer.
U.S. 2, 707, 769.	3 May 1955.	A Hall-effect magnetometer.

327. *Patents.* Abstracts in Geophysics, Vol. 21, No. 2, p. 485, April 1956.

U.S. 2, 721, 974.	25 Oct. 1955.	Flugate magnetometer.
U.S. 2, 725, 551.	29 Nov. 1955.	Fluxgate magnetometer.

328. *Patents.* Abstracts in Geophysics, Vol. 21, No. 3, p. 855, July 1956.
U.S. 2, 735, 063. 14 Feb. 1956. A self-oriented total-field airborne magnetometer.

329. *Magnetic Storm Monitor.*
W. E. Wickerham, Min. Engineer, Vol. 7, No. 10, pp. 966-968, 1955.
A magnetic storm monitor, using a fluxgate magnetometer element to detect changes in the earth's total magnetic field at a fixed location, has been developed for use in conjunction with airborne magnetometer surveys.

330. *Uses and Limitations of the Airborne Magnetic Gradiometer.*
M. Glicken, Min. Engineer, Vol. 7, No. 11, pp. 1054-1056, 1955.
The airborne magnetic gradiometer, which records the first derivative of the magnetic field with respect to time (or to horizontal distance at constant speed), helps in the location and study of certain types of magnetic anomalies found in mining geology. It should not be used independently, but rather in conjunction with regular airborne magnetic studies.

331. *A New Method for Regulating Electric Currents and its Application to Measurements of Geomagnetic Field.*
I. Yokoyama, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 31, pt. 3, pp. 211-217, 1953.
The regulation of electric currents through the Helmholtz-Gaugain coil in the GS1 magnetometer is accomplished by adjusting rheostats to nullify the current in the circuit of the standard cell. By converting the direct current to alternating current of 1,000 cycles per second and amplifying it, an audible signal may be obtained except when the circuit is balanced.
(From Geophysical Abstracts 162, U.S. Geol. Survey).

332. *The Airborne Magnetometer and its Application in Prospecting.*
A. T. Roux, Inst. Min. Metal. London Bull., No. 562, pp. 529-538, 1953.

333. *Prospecting by Airborne Magnetometer.*
P. A. Rankin, Mine and Quarry Eng., Vol. 21, No. 2, pp. 64-70, 1955.
A review of the development, techniques and applications of the airborne magnetic method with illustrations drawn from the experience of Hunting Geophysics Ltd.

334. *A Torsion-Magnetometer for Measuring the Vertical Component of the Earth's Magnetic Field.*
F. Haalck, Geophysical Prospecting, Vol. 4, No. 4, pp. 424-441, Dec. 1956.
The paper describes a vertical component magnetometer for field work whose magnet system is provided with a torsion axis and in which torsion serves as a standard of measurement. When a measurement is taken the magnetic axis of the system is brought back into the horizontal position by altering the angle of twist (null-method). The angle of twist is thus a direct measure of the vertical intensity. The instrument is within wide limits independent of the magnetic north-south direction and may therefore be set up in practically any position. The magnet system is temperature compensated, well damped and provided with an automatic clamping device. With a scale value of 25 gammas per scale division the range of the instrument for direct measurements is 65,000 gammas. A tripod of special design enables a measurement to be taken in about one minute. The weight of the torsion magnetometer inclusive of tripod is only 2.9 kg (6.4 1b).

MAGNETIC — FIELD TECHNIQUE

335. *The Airborne Magnetometer and its Application in Prospecting.*
A. T. Roux, Inst. Min. Metal. London Bull., No. 562, pp. 529-538, 1953.

336. *Prospecting by Airborne Magnetometer.*
P. A Rankin, Mine and Quarry Eng., Vol. 21, No. 2, pp. 64-70, 1955.

A review of the development, techniques, and applications of the airborne magnetic method with illustrations drawn from the experience of Hunting Geophysics Ltd.

MAGNETIC — INTERPRETATION

337. *Three-Dimensional Computations of the Vertical Gradients of the Horizontal and Vertical Components of the Magnetic Field in the Interpretations of Anomalies* (In Russian).
I. M. Pudovkin, Prikladnaya Geofiz., Vypusk 13, pp. 99-109, 1955.

Formulae are derived for the vertical gradients of the horizontal and vertical components of the geomagnetic vector at a given height over the earth's surface from measured values of the horizontal and vertical components at a lower level.

Calculations were made for the depth of the magnetic mass producing the Kursk anomalies. Assuming a dyke- like mass, the depth and width of the source was calculated using the calculated vertical derivatives at several levels. The results compared favourably with the average depth as determined by drilling.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

338. *Determination of the Depth of the Upper Surface of the Crystalline Bedrock in the (Russian) Shield Regions from Magnetic Anomalies.* (In Russian).
B. A. Andreyev, Pridladnaya Geofiz., Vypusk 13, pp. 80-98, 1955.

Magnetic anomalies discovered in the Russian shield characterize not only the geologic composition of its upper layer, but also indicate the depth and composition of the crystalline Precambrian basement. This is explained by the fact that, as a rule, these anomalies are found over the places where the deeply seated, magnetically active masses come up to the surface of the basement or even protrude from it.

Magnetic anomalies make it possible to determine the approximate depth of this boundary surface, by methods previously discussed. In such determinations it is necessary to have precise and sufficiently detailed data. For instance, with the depth to the crystalline basement from 1,000 to 3,000 m., the distance between stations must not be greater than 250 to 500 m. With these conditions fulfilled, the depth to the basement can be determined with an error not exceeding 15 %.

339. *Anomalies Produced by Sheetlike Disturbing Bodies.* (In Russian).
Yu. P. Bulashevich, Akad. Nauk S.S.S.R. Izv. Ser. Geofiz., No. 3, pp. 270-274, 1955.

Solutions of several special cases of gravitational and magnetic anomalies, using the method of direct determination, are given for anomalies produced on the surface of the earth by a vertical plate of a given thickness buried at a given depth and of infinite extent in either direction, by a plate of variable density, and by a group of vertical plates of different magnetic intensity, and the magnetic anomaly produced by a vertical rectangular prism of finite dimensions.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

340. *Combined Analysis of Gravimetric and Magnetic Anomalies and Some Palaeomagnetic Results.*
A. Lundbak, Geophysical Prospecting, Vol. 4, No. 3, pp. 226-235, Sept. 1956.

An attempt is made to interpret some magnetic anomalies in Denmark and

Northern Holland. As the thickness of the non-magnetic sediments in the areas is large, the interpretation must depend mainly on computational procedures, i.e. a combined analysis of gravimetric and magnetic anomalies, assuming that the two kinds of anomalies originate in the same body.

The mathematic basis of these computations is presented, and from this conclusions are drawn about both direction and intensity of the magnetism in the underlying rocks.

341. *New[Magnetic] Method Indicates Productive Area.*
M. Milstein, World Oil, Vol. 143, No. 6, pp. 113-115, Nov. 1956.

The author quotes the discovery of four attractive prospects in the Hainesville Dome, Texas, as an instance of the worth of a new method of interpreting a magnetic survey. It is claimed that instead of using such a survey to provide information merely on large regional variations of the magnetic field, the survey can by proper interpretation of minute cumulative effects of vertical magnetic intensities allow an assessment of the structural and stratigraphic variations in the immediate area concerned. The interpretation depends on splitting the observational curve into magnetically uniform ,,domains".

342. *Elementary Approximations in Aeromagnetic Interpretation.*
D. W. Smellie, Geophysics, Vol. 21, No. 4, pp. 1021-1040, Oct. 1956.

Total magnetic intensity anomaly expressions are derived for four simple sources: the point pole, line of poles, point dipole and line of dipoles. Type curves are presented for the point pole and dipole. For all cases, factors are calculated which may be multiplied into the half-maximum distances on the anomaly profiles to yield depth estimates. These methods serve as a first approximation in the interpretation of aeromagnetic data, but their limitations must be kept in mind. Two examples of the application of the methods are given.

343. *Interpretation of Magnetic Anomalies at Sheetlike Bodies.*
S. Werner, Sver. Geol. Urdersökning Arsbok 43 (1949), No. 6, pp. 1-130, 1953.

Well-defined magnetic anomalies frequently arise from bodies which approach sheetlike configurations, as for example, dikes composed of basic rocks. Previously the parameters for infinite sheets were calculated directly from magnetic profiles at right angles to the strike. However, only specific points on the profile could be selected, such as the maximum, minimum and inflection points. The method described here is also an analytical one, but the parameters of the sheetlike structures are determined using arbitrary points on an observed profile. Also with this method, the thickness and depth extent of the sheet may be determined. Either the horizontal or vertical field anomalies may be used for analysis. Formulae for anomalies of thin sheets of infinite and finite lengths are derived. Numerical tables of these formulae are given and numerous illustrations presented.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

344. *Some Methods of Interpretation of the Magnetic Fields.*
M. Matschinski, Geofis. Pura e Appl., Vol. 30, pp. 68-85, 1955.

The method of direct comparison of telluric and magnetic time fluctuations as well as the method of representing telluric current and conductivity in the form of characteristic ellipses is considered to involve objectionable features. A method is proposed which uses ellipse representations for the magnetic field, H, and the conductivity, λ. The method is illustrated in a 3-layer case.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

MAGNETIC — THEORY & RESEARCH

345. *Note on the Components of Magnetic Intensity at Inverse Points Relative to a Spherical Boundary.*
A. J. Zmuda, Trans. Am. Geophys. Un., Vol. 37, No. 3, pp. 273-4, June 1956.

Equations are derived which govern the relation between the values of a field component at points that are inverse relative to a spherical boundary carrying the distribution of sources. Inversions are made for surface and double layer distributions. The existence of simple relations of this character accompanies the existence of continuity of the component at the boundary.

(Author's Abstract).

346. *A Preliminary Report on Model Studies of Magnetic Anomalies of Three-Dimensional* Bodies.
I. Zietz & R. G. Henderson, Geophysics, Vol. 21, No. 3, pp. 794-814, July 1956.

Model experiments were made to devise a rapid method for calculating magnetic anomalies of three-dimensional structures. The magnetic fields of the models were determined using the equipment at the Naval Ordnance Laboratory, White Oaks, Maryland. An irregularly shaped mass was approximated by an array of prismatic rectangular slabs of constant thickness and varying horizontal dimensions. Contoured maps are being prepared for these magnetic models at different depths and for several magnetic inclinations. The fields of these three-dimensional structures are obtained by superimposing the appropriate contoured maps and adding numerically the effects at each point. The equipment and laboratory methods are described. Theoretical and practical examples are given.

(Author's Abstract).

347. *Magnetic Susceptibility of Sedimentary Rocks* (In Russian).
K. G. Bronskteyn, Prikladnaya Geofiz., Vupusk 11, pp. 163-174, 1954.

The magnetic susceptibility of about 1,600 specimens of rocks of different geologic age were determined with Kalashnikov's magnetometer.

ELECTRICAL

348. *Geoelectrical Investigations of the Graphite Deposits of Krofpmühle in the Bavarian Forest.* (In German).
F. Wilckens, Geofis. Pura e Appl., Vol. 33, No. 1, pp. 91-100, Jan.-April 1956.

The self-potential method has been used to investigate graphite deposits at Kropfmühle (Bavaria). A combination of resistivity and self-potential measurements allows qualitative conclusions on the occurrence of graphite. The general structure of this deposit is discussed.

349. *Geoelectric Exploration of Inclined Thin Beds and Ore Veins.*
F. Sumi, Geophysical Prospecting, Vol. 4, No. 2, pp. 194-204, June 1956.

The equation for the deformation of the homogeneous electrical field caused by a long inclined thin plate, is given. By means of this equation a diagram is designed for the direct depth determination of the upper and the lower edge and for the inclination of the plate. The equation and the diagram are proved by small scale model measurements and applied in field exploration.

(Author's Abstract).

350. *Potential and Apparent Resistivity over Dipping Beds.*
J. C. De Gery & G. Kunetz, Geophysics, Vol. 21, No. 3, pp. 780-793, July 1956.

The potential field due to a point source of current, located on the surface of the earth near a dipping bed, is given in an exact expression and modified expressions are developed for computations. These expressions lead to graphs of the potential field and to apparent resistivity vertical profiles which are presented. The Schlumberger electrode configuration is used. This configuration consists of two current electrodes and two potential electrodes, the latter placed close enough together that the current density between them can be considered to be uniform. With this configuration oriented perpendicular to the strike of the dipping bed, the apparent resistivity is paradoxical in that it approaches either zero or infinity as the electrode separation increases without limit.

(Author's Abstract)

351. *Physical Causes of Errors in Vertical Electrical Sounding Using the Compensating Method.* (In Russian).

A. N. Tikhonov & B. G. Enenshteyn, Prikladnaya Geofiz., Vol. 10, pp. 74-83, 1953.

Theoretical and experimental studies on the physical causes of errors in d-c electric profiling with a potentiometer as the measuring instrument are discussed. By using an oscillograph the building up of the current and the voltage have been observed, and it is concluded that when a potentiometer and dry batteries are used the errors of measurements are very often high, as when the electrode spacing exceeds 10,000 meters the final value of the voltage is reached in about 20 secs., and to take readings after such a lapse of time is usually impossible because of disturbances created by stray currents. Therefore, the elimination of errors due to the slow building up of voltage is possible only when oscillographic recording and an electric generator of sufficient capacity are used.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

352. *Geoelectric Soil Investigations Based on Several Borings.*

(In Hungarian with English and Russian Summaries).

L. Szabadvary, Magyar Allami Eötvös Lorand Geofiz. Intezet, Geofiz. Kozlemenyek, Vol. 3, No. 9, pp. 121-141, 1954.

This discusses a new method of interpreting electrical depth profile where several boreholes are available in the area under investigation. The method concerns surface soil problems involving shallow depths and very precise determination of layer boundaries.

(From Geophysical Abstracts 164, U.S. Geol. Survey).

353. *On the Point Source of Direct Current in Heterogeneous Half-Space.* (In Russian).

D. N. Chetaev, Akad. Nauk S.S.S.R. Izv. Ser. Geofiz., No. 3, p. 265-266, 1955.

The problem discussed is the determination of the pattern of the electrical field generated in the ground by a dipole fed by a continuous source. The ground with respect to its electric properties is considered as a sectionally differentiable semispace. By following the procedure suggested by Tikhonov, differential equations are derived representing the physical conditions of the problem and by use of the theory of complex variables after a solution is found in finite form.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

354. *The Transient Electromagnetic Field Produced in a Stratified Terrain by a Pulsating Vertical Magnetic Dipole.* (In Italian).

A. Belluigi, Ser. Geol. Italia Boll., Vol. 75, (1953), fasc. 2, pp. 913-926, 1954.

Determination of the pattern of the electromagnetic field produced in a horizontal stratified terrain by a pulsating vertical dipole (a horizontal circular loop) is closely related to the problem of the transient electromagnetic field produced by a horizontal electrical dipole, previously solved by Belluigi, and the solution is given as a simple corollary. Wait has also solved the problem by a different method.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

355. *Analytic Method of Treating Field Data in Surveys Made by the Telluric Current Method.* (In Russian).
A. P. Bondarenko, Akad. Nauk S.S.S.R. Izv. Ser. Geofiz., No. 3, pp. 267-269, 1955.

In this method of exploration, ellipses are graphically constructed representing the variations of the vectors measuring the intensity of the electrical field. An analytical method of this determination is suggested, similar to a Fourier harmonic analysis, and is explained by an example. It takes less time to perform the computations than to construct the necessary ellipses. The method can be applied also when the field vector is linearly polarized.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

356. *A Resistivity Survey in Scotland.*
S. A. Vincenz, Colliery Eng., Vol. 31, No. 362, pp. 157-163, 1954.

357. *Geophysical Prospecting by the Use of Alternating Emitters and Fields in the Ground for Different Kinds of these Emitters.* (In French).
A. Belluigi, Acad. Sci. Paris Comptes Rendus, Vol. 240, No. 16, pp. 1657-1659, 1955.

In this note a few characteristic properties of the electromagnetic fields of different emitters are indicated, and a solution is given for the problem of the single-electrode emitter.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

358. *Geophysical Experiments on the Island of Capri and on the Sorrento Peninsula.* (In Italian).
G. Zaccara, Ser. Geol. Italia Boll., Vol. 76, No. 1, pp. 315-321, 1954.

359. *Electrical Depth Profiling Studies of the Miocene Basin of Northern Gharb.* (In French).
C. Aynard & M. Arnaud, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, fasc. 9, pp. 217-229, 1954.

360. *Five Years of Electrical Exploration in North Africa for Hydrologic Research.* (In French).
J. J. Breusse, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 9, Fasc. 9, pp. 191-209, 1954.

361. *Principles of Geoelectric Equivalence and the Erroneousness of some Composition Laws Regarding Electrical Sounding of Multi-Layered Structures.* (In Italian).
A. Belluigi, Geofis. Pura e Appl., Vol. 34, No. 2, pp. 57-65, May-Aug. 1956.

The author explains as a synthesis some of his own results concerning the equivalence principles of electrical sounding and the erroneousness of some composition laws regarding multi-layer structures.

GEOCHEMICAL

362. *Patents.* Abstracts in Geophysics, Vol. 21, No. 3, p. 854, July 1956.
U.S. 2, 733, 135. 31 Jan. 1956. A method of analyzing soil samples.

363. *Present-Day State of Geochemical Prospecting of Oil Formations in U.S.S.R.* (In Russian).
J. J. Glogoczowski, Nafta (Krakow), Vol. 10, pp. 211-213, 1954.

Early work in soil analysis aimed at finding hydrocarbons in the soil. Present-day work concerns itself with mutual action of hydrocarbon gases on soil and vice versa, as well as on micro-organisms which help such action. Certain ideas now discarded are described, together with the most up-to-date methods.

364. *Geochemical Investigation of Crude Oils.*
L. C. Bonham, Bull. A. A. P. G., Vol. 40, No. 5, pp. 897-908, May 1956.

A spectrochemical study was made of 66 crude-oil samples from different parts of the U.S. to investigate the geological significance of trace metals in oils. Among the oils analyzed, those from some basins contain distinctly different trace-metal suites, but oils from basins of similar age and environment do not show characteristic differences.

365. *Test of Geochemical Prospecting by Analysis of Adsorbed Gas on the Gouaro Anticline.* (In French).
M. Louis & R. Pomeyrol, Rev. Inst. Franc. Petr., Vol. 10, No. 9, pp. 1053-56, 1955.

RADIOACTIVITY

366. *Patents.* Abstracts in Geophysics, Vol. 21, No. 2, p. 485, April 1956.

U.S. 2, 721, 943.	25 Oct. 1955.	A gamma-ray detector using a translucent liquid luminophor and a gas-filled photo-electric detector to produce gas amplification of the scintillations.
U.S. 2, 721, 945.	25 Oct. 1955.	A radioactivity prospecting method in which radiation is measured just above the surface of the ground.
U.S. 2, 722, 610.	1 Nov. 1955.	A radioactivity prospecting method in which the natural gamma rays impinge on a foil, producing beta rays whose energy distribution is measured.
U.S. 2, 724, 060.	15 Nov. 1955.	A gamma-ray detector.
U.S. 2, 725, 484.	29 Nov. 1955.	A scintillation counter.
U.S. 2, 727, 154.	13 Dec. 1955.	A scintillation counter.

367. *Instrumentation and Methods for Radioactivity Detection in the Mineral Industry.*
J. O. Milmoe & S. P. Kanizay, Q. Colorado Sch. of Mines, Vol. 51, No. 1, 97 p, January 1956.

This issue of the quarterly is in two parts. The first, by Milmoe, deals with the theory, development and applications of various radioactive detection instruments. Some special uses devised by the Colorado School of Mines Research Foundation are pointed out and explained. The second part, by Kanizay, is an outline of current exploration techniques, assessing the advantages and limitations of each. An appendix includes considerable source information on radioactive exploration and exploitation.

368. *Patents.* Abstracts in Geophysics, Vol. 21, No. 3, p. 855, July 1956.

U.S. 2, 733, 355.	31 Jan. 1956.	A scintillometer for measuring thermal neutrons.
U.S. 2, 735, 946.	21 Feb. 1956.	Radioactivity prospecting method by traverse.
U.S. 2, 735, 953.	21 Feb. 1956.	A multiple-cathode Geiger-Mueller detector.
U.S. 2, 738, 431.	13 Mar. 1956.	A multiple-cathode Geiger-Mueller detector.
U.S. 2, 739, 242.	20 Mar. 1956.	A radioactivity detector employing a scintillometer and a cosmic ray detector.
U.S. 2, 739, 286.	20 Mar. 1956.	An ionization chamber amplifier for an alpha survey meter.

369. *Geophysical Prospecting by the Use of Radioactivity Surveying.*
G. Herzog, Mines Mag., Vol. 46, No. 1, pp. 25-28, 1956.

Radioactivity surveys conducted on foot revealed that known faults could be located by that method with reproducible results. These earlier investigations were followed by carborn and airborne radioactivity studies. Both multiple cathode and scintillation counters were used. It was found that radioactive ore deposits buried beneath the surface apparently cause radiation anomalies detectable at the surface. In the airborne work favourable results were obtained at flight elevations between 75 and 800 ft. with some of the best results at about 150 ft.

Radioactivity surveying has been useful not only in prospecting for radioactive ore deposits, but also in prospecting for base metal deposits and in geologic studies. Faults, sedimentary igneous contacts, and other geologic features are often revealed by radiation anomalies.

(From Geophysical Abstracts 164, U.S. Geol. Survey.)

370. *Scintillation Detector for Carborne and Airborne Use.*
F. J. Davis et al, Nucleonics, Vol. 12, No. 12, pp. 46-47, 1954.

A description, with circuit diagrams, of a scintillation detector for geologists and prospectors. The equipment weighs 31 pounds, not including the recorder and scintillation head, and is operated from either the 6-volt or 12-volt storage battery of any car or light aircraft.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

371. *The Possibility of the Application of Radioactive Method in Exploratory Geology.* (In Russian).
K. Przewlocki, Przeglad Geol. Zeszyt 6, pp. 295-296, 1955.

A brief review is given of radioactive methods of exploration and their possible applications in geophysical exploration. An extensive bibliography of the subject is given as an appendix.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

372. *Radioactive Method for Geological Exploration.*
Z. Hatuda, Kyoto Univ. Coll. Sci. Mem., Ser. B. Vol. 21, No. 2, pp. 231-271, 1954.

Radioactive prospecting as here described is the determination of geologic structure by measurements of radioactivity. Four methods are used: determination of radon in soil air; measurement of ionization in a hole in the ground using an electroscope; using photo plates inserted into the hole; and measuring by Geiger counter.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

373. *Aerial Detection of Radioactive Mineral Deposits.*
A. F. Gregory, Canadian Min. Metall. Bull., Vol. 48, No. 520, pp. 479-485, 1955.

Airborne Geiger counters and scintillation counters have been used by the Eldorado Mining and Refining Ltd., since 1947, and extensively so since 1949. Several limiting conditions were established for successful radioactivity detection, the most important being that natural vein exposures can only be assuredly detected at distances of less than 150 ft. Sedimentary and pegmatite radioactive deposits can be detected at greater distance. Helicopters offer a useful aerial prospecting possibility.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

OTHER METHODS

374. *On a Device for Electrochemical Investigation of the Subsoil.* (In Italian).
N. Orilia & G. Petrucci, Geofis. Pura e Appl., Vol. 33, No. 1, pp. 101-110, Jan.-April, 1956.

A method of electrochemical prospecting by induced polarisation of the soil is described. Field and laboratory experiments are reported which give evidence of the practical value of this method.

375. *Note on ,,Geophysical Prospection of Underground Water in the Desert by Means of Electromagnetic Interference Fringes."*

G. L. Brown, Proc. I.R.E., Vol. 44, No. 7, p. 940, July 1956.

The paper by M.A.H. El-Said is the subject of this note. It claims an oversight of the attenuation constant in the propagation equation, develops this constant and shows how this effects the final results.

A rebuttal from Dr. M.A.H. El-Said follows immediately. This denies any oversight and explains how the former conclusions were arrived at.

IN DEFENSE OF MINING GEOPHYSICS *)

BY

E. H. HEDSTRÖM **)

The first object of our Association is, according to its Constitution, to promote the science of geophysics as it applies to exploration. To attain this object it is evidently necessary that we sell to the industry the idea that geophysical prospecting is a timesaving and economical aid to exploration for oil and minerals, and to the young students we must sell the idea that our profession offers attractive careers. Only then can we count on having enough money and manpower to promote effectively exploration geophysics.

Now the publicity for geophysical exploration within the petroleum industry has been excellent for a long time. And as to the students, the American petroleum industry three years ago sponsored a very fine brochure entitled "Careers in Exploration Geophysics", which was sent to every high school and university in the United States.

When it comes to mining geophysics, however, the publicity has, in comparison, been rather poor. It is true that on the American side the annual reviews in mining journals after World War II, especially in the last few years have reported favourably on the ever increasing activity in mining geophysics. And likewise, the authors of the annual report of the Standing Committee on Geophysical Activity of the Society of Exploration Geophysicists, our American sister organization, have in recent years repeatedly commented more favorably on the growth of mining geophysics than on the increase in geophysical exploration for oil. I quote Sigmund Hammer: "The greatly increased utilization of mining geophysics in 1954 is an encouraging sign of healthy growth. The reported statistics are undoubtedly conservative because some mining companies that are known to be doing geophysical exploration have not reported to the Committee. We can look forward with confidence to great expansions in the field of mining geophysics in the years to come". And Homer G. Patrick, in his interim report for the first half of 1956 concludes: "It is evident that the role of geophysics in explorations for minerals is becoming an increasingly important one. Further expansions in the employment of geophysical methods by the mining industry is expected". But there has been a "considerable reluctance to publish or even to announce findings based on geophysics" and very few case histories have up to now been published. Furthermore, on this side of the Atlantic, authors dealing with mining geophysics have often been remarkably pessimistic in their views on this technique and its future.

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*) Presidential Address delivered at the Twelfth Meeting of the European Association of Exploration Geophysicists, held in Brussels, 5-7 June, 1957.

**) A.B. Elektrisk Malmletning, Stockholm.

It is for this reason that I have chosen as the subject of my address the development, especially during the last six or seven years, of geophysical prospecting outside the field of petroleum exploration. As a title I have chosen "In defense of mining geophysics", because I want to correct, at least try to correct, some misconceptions that might have been in vogue, about geophysical prospecting in the mining field.

As a starting point for my discussion I will take some views expressed in a little booklet on geophysical prospecting that I picked up in Paris, to use as reading matter on a plane, just about the time when the first steps had been taken to form our Association. It was a new book at the time, the last volume in a popular series on the different sciences, and I found it both entertaining and well written. But, about mining geophysics the author was *very* pessimistic. He stated that mining companies allot very little money to geophysical exploration, that those clients have an unfavorable psychological attitude which makes the mining field unattractive to the geophysicist, that the problem to solve will nearly always be difficult, with very small chances for success, and that the surest reward for the prospector will be reproaches and an unfavorable publicity. When I had read that far I turned back to the foreword where it was said that the book was meant as an introduction to exploration geophysics for mining engineers, geologists, petroleum engineers, even capitalists, and that it was also written for students or future students who might feel attracted by "the captivating, sporting and lucrative career" of exploration geophysicist. Then I thought that this was indeed unfavorable publicity for mining geophysics, because those students or future students would certainly not consider it as a vocation, nor would the capitalists think much of its use for exploration.

The booklet also stated that the technical development in mining geophysics has been at a standstill, because the big geophysical companies have not had an incentive to make a technical effort in the mining field comparable to that which they have done to perfect the methods for oil prospecting. If I may quote verbatim in translation: "While, year after year, petroleum geophysics makes notable progress, mining geophysics, remains, in the year 1948, approximately in the same state where it was in 1918 etc."

This made it clear to me that the author simply did not know about the great technical development in mining geophysics, in the early days, say between 1922 and 1929, about the corresponding increase in the volume of application and about the string of important ore discoveries made already at that time through this new geophysical technique. Nor was he aware that mining geophysics was well on its way towards staging a comeback when his book appeared. The statement that research and development are neglected in mining geophysics now looks very peculiar against the background of the statistics published in "Geophysics", since 1948. We find there that the expenditure for *research* in mining geophysics in later years is of the order of 15 percent of the total expenditure for operations, in terms of man-months even some 25 percent of the total. These are, as we all know, very much higher figures than in geophysical oil exploration. They may show that mining geophysics is still developing, that it is not in a ready shape as a technique, but they certainly do not bear out the contention that the technical effort in development and research is neglected—on the contrary.

If we take a look at the progress in geophysical technique in these few years, we note first of all the advent of the airborne methods, magnetic, electromagnetic and radiometric. This is a very important development, much of it very recent, which has also helped to bring about an interesting and gratifying change in the outlook of top exploration management. I will revert to that later. We also note new ground magnetometers of the torsion-wire type and of the fast electronic type. Further we have the new inductive electromagnetic ground equipment, of low weight and high versatility, which measures all field components at two frequencies and can be used by field parties consisting of only two men. There is also a host of new equipment for uranium prospecting, some of it on a very high level technically. Equipment for geophysical work in diamond drillholes exists and is being perfected. Great advances have been made in field procedure and interpretation, for instance in geochemical field techniques, in the use of the seismic refraction method in areas with inhomogeneous overburden, and so on. These are just a few examples to illustrate the fact that mining geophysics is in a stage of rapid development and expansion.

From the statistics published by S.E.G., we can also learn that geophysical activity in the mining industry, measured by the corresponding expenditures, has been growing during the last five years at the average rate of some 20% per year, which means doubling its size in four years, while at the same time oil geophysics has been growing at a much lower rate, some 5% per year on an average. Consequently, mining geophysics is certainly not falling behind in the general growth of geophysical exploration, as has been stated—on the contrary, the proportion of geophysical work devoted to mining and civil engineering increases at a fast rate.

But how is it then that the activity in mining geophysics is so very small when compared to geophysical exploration in the petroleum industry? Well, before we take it for granted that mining geophysics is backward and underdeveloped, let us have a look at the relative sizes of the possible markets for geophysical exploration in the mining industry on the one hand and in the petroleum industry on the other. In both cases geophysical work is of course only an adjunct to the exploration activity of the industry; in the U.S. petroleum industry for instance the geophysical expenditure amounts to 10 percent or less of the total exploration cost. Now the mining industry has on the whole been much less exploration-minded than the oil industry, because its ore reserves have been considered to be so large. Out of the total value of the mineral production in the western world in 1952, the last year for which complete statistics appear in the Minerals Yearbook, about 75-80 percent can be estimated to have come from deposits that were known and worked before 1920, in "pre-geophysical" times. The average mining company, up to quite recently, has had ore reserves to last for a couple of generations, and with the probability of extensions of the reserves in the course of regular mining work, it has not had to worry too much about exploration. And where exploration has been going on, in an organized and orderly manner, the annual expenditure for this activity has generally not been higher than, say, two percent of the product value of the mines. This is, for instance, the case with a large base metal company in Sweden, which is completely dependent on the results of its exploration, but which still finds it sufficient to spend only 1½ percent of its annual product value from the mines on exploration activities, out of which one quarter is devoted to geophysical work. For the entire mining industry in Sweden the figure is somewhat less than one percent; in Canada the figure seems to be about two percent. In the petroleum industry, on the other hand, exploration is a matter of life or death, because the reserves of the average oil company dwindle very fast: most of the oil produced today comes from discoveries that were made within the last 10 or 15 years. For this reason the petroleum industry *has* to be exploration-minded, and as an example we may take the petroleum industry in the U.S. which spends no less than 40% of its annual product value on exploration, out of which one tenth, or 4% is for geophysics. The petroleum industry therefore seems to allot some 20-40 times more to exploration than the mining industry, in relation to annual product value. Since the product value of the petroleum industry in the western world is about twice the product value of the metal mining, this would mean that the market for oil geophysics should be 40 to 80 times larger than for mining geophysics. Now the expenditure for petroleum geophysics is actually, according to the SEG statistics, some 50 times higher than for mining geophysics. This would indicate, then, that mining geophysics has been holding its own and getting at least the same proportionate share out of its small market, as petroleum geophysics is getting out of its big market. In fact the share of geophysics in mining exploration seems frequently to be rather of the order of 15-30%, instead of 10% as in oil exploration (maybe chiefly because drilling and other exploratory work is lagging behind).

That the mining industry should be able to spend so comparatively little on exploration, even where it is completely dependent on new discoveries, indicates that the cost of finding new ore is very small, compared to the finding costs for petroleum. (The development cost is quite another matter). And a look at figures given in the literature seems to bear this out. In the petroleum industry of U.S.A., the geophysical expenditure was estimated, a couple of years ago, to be about 5 cents per barrel of oil discovered, including the extensions of reserves through drilling of previously known fields. This, then, would correspond to 20 barrels or about $ 50 for every geophysical dollar invested. Other estimates, as in the Petroleum Engineer 1953, indicate figures of 12-15 barrels, or $ 30-40 corresponding to the investment of one geophysical dollar. (Thus we may count with a ratio of return of between 30 and 50 to 1.) Six years ago there appeared an article in "Mining Engineering" based i.a. on statistics sent in from South Africa and Sweden, which showed that the ratio of return on the geophysical dollar in ore prospecting in these countries was of the order of several hundred to one. One big mining company in Sweden, for instance, listed eleven discoveries over 21 years of exploration, with a *minimum* value of 236 million dollars against a cost of *all* their geophysical work during the same time of 1.3 million dollars, a ratio of 180: 1. For fifteen years of magnetic work in Central Sweden another company reported a ratio of return of 5800 to 1. From South Africa it was reported that geophysical work during 16 years with a total expenditure of about $ 1 million had resulted in discoveries worth 1400 million dollars. A balance struck between South Africa and Sweden, the total expenditures being of the same magnitude, indicated a return of 500 dollars worth of ore discovered per every dollar spent on all the geophysical work in these two countries. Two years ago, in the annual volume published by Fomento Mineiro of Portugal, a government institution, there was an article describing the results of five years of electromagnetic prospecting for pyritic deposits in Portugal, using only one simple method for reconnaissance purposes. It reported that drilling in one district on an electromagnetic anomaly had struck a big commercial orebody where there was no sign on the ground or rock surface of any mineralization. The total value of this body and of an adjacent orebody, found through the underground exploratory work on the geophysical discovery, was estimated to be about 100 times the total expenditure for all the five years of geophysical work. Further drilling and exploratory work on these two bodies up to now is said to have increased the tonnage so much that the latest figure indicated for the return on the geophysical dollar is over 550. You will note that these examples refer to serious exploration campaigns of many years' duration and that all the costs of geophysical work over barren areas have been included, while the value of the mineral deposits found has been estimated by analogy to the previously mentioned figures for the petroleum industry. There are also many examples of more limited geophysical campaigns that have led to rich discoveries. Among the articles that we are now collecting for a Volume on Case Histories in Mining and Civil Engineering Geophysics there is one describing two important discoveries made in Yugoslavia in the last 6 or 7 years, where the value of the ore found must be thousands of times higher than the cost of the geophysical work that led to the discoveries.

Here one might stop to ask: "If mining geophysics is doing so well, why then the pessimistic views in that booklet mentioned at the beginning, and which was published only seven years ago?" In reply I would say that the author's views are understandable if one assumes that he was looking back to the past. It *was* difficult to make mining companies spend money on geophysical work, and the old mine managements *did* show a certain attitude of mistrust towards geophysics. In part this was probably due to the overselling of geophysics, in the late twenties, to mine managements who did not know what to make of it; notably in Canada a lot of bad work of this kind was done in the hectic days of speculation before the great financial crash at the end of 1929. The aftermath of that was felt for twenty years, and with the predominance of American publicity in our profession, up to recently, that North American setback has doubtless influenced thinking also in Europe.

But times have changed. In the first place it has been realized, especially after the report of the Paley-Commission of 1951-52, that the enormous increase in consumption of minerals, parallelling the growth of industrial production, makes the reserves appear alarmingly small. The exploration activity in the mining industry is, therefore, now rising fast, and this makes for a quickly growing market for mining geophysics. Further, mine managements today are frequently recruited from a younger generation which has mostly had some course in exploration geophysics at their mining school. The situation is therefore nowadays much more favourable, than previously, to serious geophysical companies of good repute, because they need no more be classed along with the charlatans. Besides, there is today at hand a number of reliable geophysical consultants, who can act as links between their clients, the mining companies, and the geophysical contractor. This was referred to by our retiring president two years ago as a good solution out of certain difficulties. It is certainly a good solution for the first problem that meets the mining geophysicist who is employed in a contracting company, each time a new case comes up: whether to recommend a geophysical survey, perhaps only a test survey, or whether to advise against the use of geophysics.

The most important and promising change for the better—at least so it seems to me—is that new fashion among the mining companies to set up their own exploration departments, complete with geologists, geophysicists, and mining engineers. This does completely away with the psychological problems between geophysicist and client, to which our President two years ago directed our attention, to wit, the lack of understanding and cooperation from the client's side. It might also make for longer and more well-planned jobs for geophysical contractors—by analogy with what is usual in the oil industry—and it will certainly tend to promote the science of exploration geophysics in the mining field. This new development seems to have turned into a regular movement in America, where until recently even the big mining companies could afford to rely on the findings of the old type individual prospector. Between 1946 and 1950 three big American mining companies had set up exploration departments, in 1950 two more followed suit, and in the last six years five other companies have joined the movement, among them some of the biggest and most famous mining companies of the world. The reason that this new way of thinking has been adopted in such a comparatively short time is probably not only the realization that ore reserves after all are pretty small, that the areas where outcrops can be found have already been explored and that prospecting must now be extended to areas covered with overburden of one type or another, where the old-time prospector can do nothing. When a few big mining companies have gone in for this new policy, this also introduces a competitive element, because other mining companies find that they cannot only sit by and wait while their competitors are helping themselves to all the important orebodies in new exploration areas. And the knowledge that the new airborne geophysical methods can be used to run over large areas in a comparatively short time, to "skim off the cream", as it were, adds to the concern of those mining companies who are lagging behind in this "armament race" and makes them hurry to set up similar exploration departments. This competitive element in turn tends to incite an increased effort in exploration. It seems therefore highly probable that the market for mining geophysics in the world as a whole is going to increase considerably in the near future.

From the figures I gave before it is evident that there is very much room for such an expansion in the mineral exploration activity; when the new type mine managements to which I referred before, realize that maybe several percent of the annual product value from their mines could be used for exploration in order to secure a basis for their company's future (against the 40% used by the petroleum industry) and that exploration campaigns should be planned for years ahead, irrespective of short-range fluctuations in the metal prices, then the market for mining geophysics is bound to increase even faster than it has been doing in the last five years. This will provide means for further technical development and provide jobs for increasing numbers of young geophysicists. And seeing that this development is in full swing elsewhere, it seems that a strengthening of the European effort in mineral prospecting cannot be avoided in the long run, especially if a more or less united Europe is to be responsible for developing the resources of the interior of the great continent of Africa.

ACKNOWLEDGEMENT

Before preparing this address I corresponded or had discussions with various people to whom I herewith want to express my appreciation and thanks, especially to J. Eklund, A. A. Rocha Gomes, R. C. Holmer, D. Malmqvist and F. Sumi.

THE USE OF NEAR SURFACE TEMPERATURE MEASUREMENTS FOR DISCOVERING ANOMALIES DUE TO CAUSES AT DEPTHS*

BY

O. KAPPELMEYER **)

Abstract

In this paper an attempt has been made to evaluate the possibilities of determining subsurface features from temperature measurements made at shallow depths. The temperatures at the observation depth used are subject to seasonable variations. The amount of this variation differs, and these differences have been attributed to structural features. Local differences in temperature are also caused by surface factors such as the thermal conductivity of the soil, the vegetation and the micro-climate. The differences in temperature due to surface factors are so great that the variation in heat flow caused by differing thermal conductivities of the rocks at depth cannot be detected at the surface. It is not possible therefore to use this method to determine the position of subsurface structures such as domes, anticlines or horsts.

It is also shown that concentrations of radioactive elements in the rocks do not provide any measurable heating.

The method has been successfully applied to the problem of finding fissures, cracks and similar features provided that convective heat transport from depth to the surface has taken place along these features. In order to compute the area through which a given amount of water at a given depth must pass to give a specific temperature increase a model has been considered. From the shape of the temperature anomaly above a fissure carrying such heated water, the places at which the rising water enters the groundwater stream can be seen immediately. It is possible to estimate the amount of rising water by computing the amount of heat energy transferred to the surface.

The method is particularly suitable for determining the position of steam deposits in regions of recent vulcanicity. In such a region a location, hitherto unknown, was found where steam rising from depth condenses beneath the surface.

The area and form of the anomaly indicate the extent in depth of this steam bearing zone. By means of observations made at the individual points, it was also possible to compute approximately the energy being released at the surface. This value can give an indication of the extent to which the steam deposits regenerate themselves.

Finally it has been shown that percolating canal water can be detected thermally near the canal banks. Such anomalies are dependent on the season.

Introduction

In the earth's crust as far as it is known to us, the temperature rises with increasing distance from the surface. This increase is related to the heat flow towards the surface. An examination is made of the circumstances in which the heat flow is so disturbed that anomalies are caused which can be delineated by temperature measurements made very near the surface.

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*) Part of this paper was presented at the Tenth Meeting of the European Association of Exploration Geophysicists, held in Hamburg, 16-18 May 1956.

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As temperature differences at shallow depths are due both to subsurface and surface effects, the latter are discussed first. The possibility of eliminating them from the observations by applying corrections is investigated. It is found that a fairly large part of the surface effects cannot be eliminated, and the magnitude of the remaining surface effects is the factor which restricts the field of application of geothermal measurements.

Measurements have been made at a depth of 1.5 m. At this depth resistance thermometers allow the temperature to be taken simply, quickly and cheaply, with an accuracy of ± 0,05° C. A schematic representation of the measuring arrangement is shown in fig. 1.

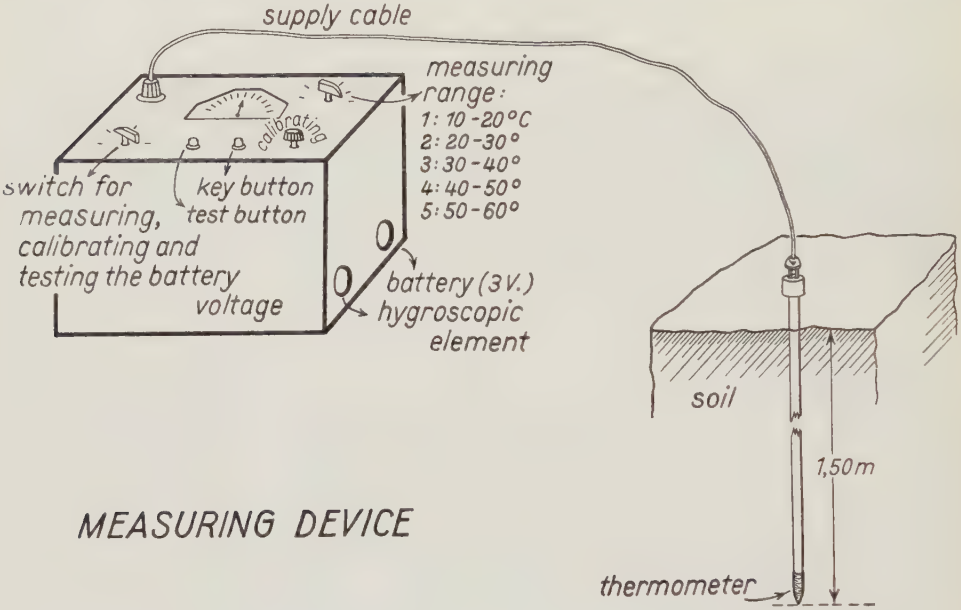

Fig. 1. Diagramatic representation of the measuring arrangement

The temperature range at the observation depth

General

To find the temperature anomalies it is necessary to compare the measured temperatures with a standard value. The minimum anomaly detectable depends on the accuracy with which the standard temperature for a measuring area is known at each observation point.

In this connection the standard value of the temperature is taken to be a value representing the temperature at the observation depth when there is no heat flow from depth to the surface. It is shown later that the influence of the normal natural heat flow on the temperature at the observation depth can be neglected.

Initially, therefore, the temperature in the near surface layers is examined assuming that there is no heat flow from depth to the surface.

With this limiting condition, which is almost always fulfilled in nature, the temperature at the observation depth depends on the heating and the cooling of the surface. The most important temperature changes at the surface, which are propagated through the ground, are the regular diurnal and annual variations. The amplitude, phase and shape of the temperature oscillation at a certain depth depends on complicated conditions at and above the surface (Geiger 1950) and also on the nature of the soil. In our latitude the diurnal periodic temperature variations can be detected down to a depth of 75 cms, so that they do not directly affect the temperatures at the observation depth.

Thus the annual variation is the most important influence on temperature at the chosen depth. In most publications concerned with these phenomena, the average of observations over several years has been given and discussed, mainly by meteorologists. (Mütterich 1880, Leyst 1890, Keränen 1929, Schubert 1930, Toperczer 1947).

However, as the actual values, rather than a smoothed average of the temperature in the ground are required, the results for a chosen year are given here.

Observations made near Hanover show that, as one would expect from theoretical considerations, irregular variations of temperature at shallow depths approach a pure sine wave oscillation with a period of one year as the depth increases (fig. 2). The diagram shows the observed graph together with the first harmonic computed by harmonic analysis. The deviation of the observed curve from the first harmonic is of interest as, in general, only the first harmonic can be computed analytically. (The number of component waves which can be computed analytically depend on the number of measurements made at a given station). The amplitude of the temperature variation decreases with depth and the oscillation suffers a phase shift. The irregularities in the observed curves are due in this case to an instrumental error of ± 0.2° C.

Theoretically an arbitrary temperature variation can be represented by the following equation:

$$\vartheta(z, t) = \sum_{n=1}^{n=\infty} \vartheta_n \, e^{-w_n z}, \cos \left(2\,\pi n \,\frac{t}{T} - w_n z - \gamma_n\right) + \bar{\vartheta} \tag{1}$$

ϑ_n = Amplitude of the nth harmonic at the surface

z = depth

m = thermal diffusivity

$w_n = \sqrt{\dfrac{n\,.\,\pi}{mT}}$

T = one year (period)

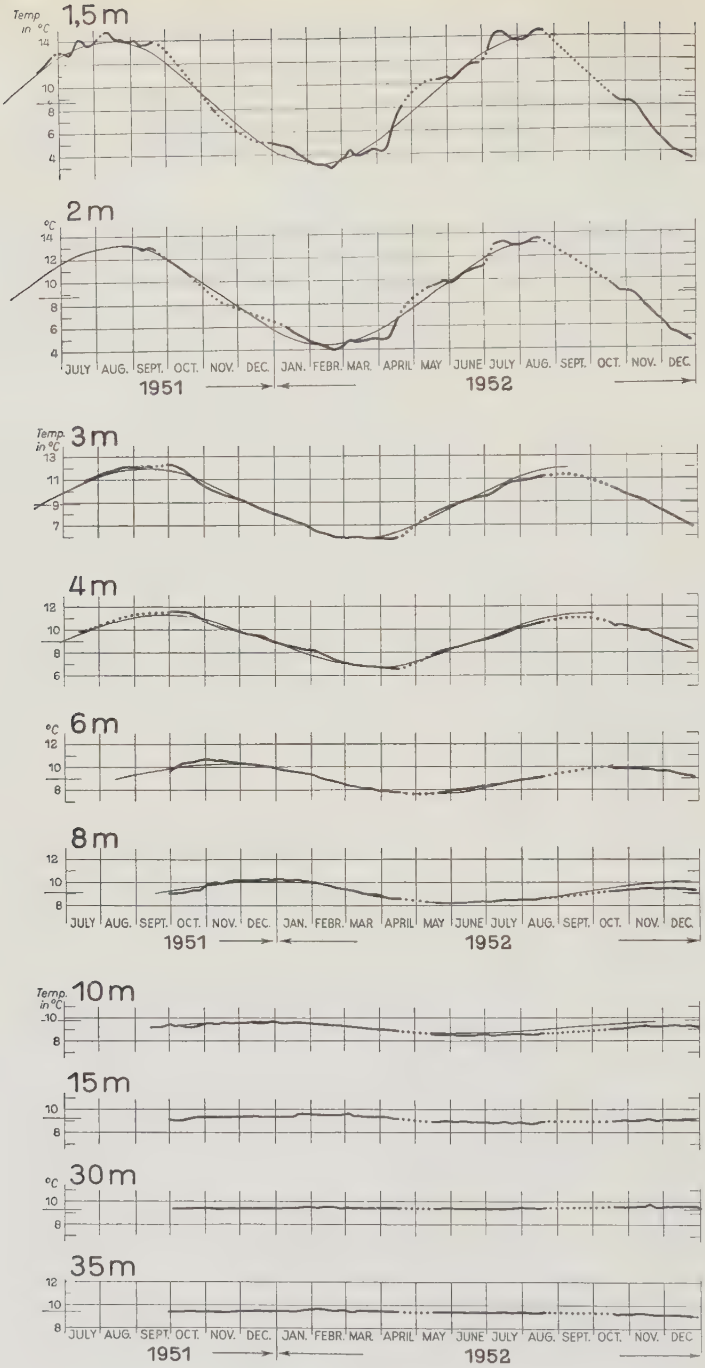

Fig. 2. Annual temperature range measured at various depths.

— measured graph

— first harmonic

t = time
γ_n = phase of the nth hamonic
$\overline{\vartheta}$ = mean annual temperature

The temperature range at the surface or at any depth can be represented by a Fourier series. The individual terms of this series follow from the equation of heat conduction. The amplitudes of the component waves decrease exponentially, the short waves decaying more rapidly than the long waves. The exponent is dependant on the period of the oscillation and on the diffusivity of the soil. With an equal diffusivity the short period diurnal variation will decrease to half its surface amplitude in $1/\sqrt{365} = 1/19$ of the depth for the corresponding reduction of the first harmonic of the annual variation. Similar figures apply to phase shift.

The equation shows that the temperature measured at a given depth at a certain time depends on:

1. The thermal diffusivity of the soil
2. The amplitude and the phase of the fundamental and the component waves of the temperature variation curve
3. The mean annual temperature.

It was necessary to discover how far these properties change within the area surveyed, how the changes effect the temperatures at the depth of observation, and also how far the local differences could be determined by repeated measurements spread over the year, or by measurements at various depths. In these investigations the long period observations of various meteorologists named above were used, supplemented, as far as possible, by further measurements.

Magnitude of Temperature Variations due to Surface Effects

The influence of local diffusivity variations

By differentiating equation (1) we obtain the temperature change, $\pm\,\Delta\vartheta$, which corresponds to a change in the thermal diffusivity of $\pm\,\Delta m$. Only the first harmonic, with the amplitude ϑ_1, will be considered and the time origin will be chosen so that γ_0 is zero. We then obtain:

$$\Delta\vartheta = \pm\,\tfrac{1}{2}\,\vartheta_1 \frac{1}{m}\sqrt{\frac{\pi}{mT}}\,z\,e^{-\sqrt{\frac{\pi}{mT}}z}\left\{-\sin\left(\frac{2\pi t}{T}-\sqrt{\frac{\pi}{mT}}\,z\right)+\cos\left(\frac{2\pi t}{T}-\sqrt{\frac{\pi}{mT}}\,z\right)\right\}\Delta m.$$

Disregarding extreme conditions such as massive granite and marshy soil, we find values for the thermal diffusivity lying between 0,005 cm²/sec and 0.013 cm²/sec so that $\Delta m = \pm 0.004$ cm²/sec.

For the amplitude of the first harmonic at the surface of the earth at 16 German open-air stations, Bartels (from *Handbuch der Bodenlehre* by Schubert) found, using observations made over many years, $\vartheta_1 = 9.1°$ C.

If these values of ϑ_1 and Δm are substituted in the equation and if a mean value of m of 0.009 cm²/sec is used, we find $\Delta\vartheta$ as a function of time. At a depth of 1.5 m, the greatest effect as the temperature is given by $\Delta\vartheta = \pm 0.7°$ C. From the equation, the time at which the influence of the variation on the temperature becomes a minimum, can be computed.

This minimum can be zero if two different temperature diffusitivities only occur in the measuring area. In practice, this is never the case.

The effect of local variations in the surface temperature range.

Changes in the temperature range at the surface of the earth in flat areas are caused mainly by differences in the vegetation. Bartels (from *Handbuch der Bodenlehre* by Schubert) gives the following deviations from the annual average, based on observation over many years:

At the surface in open fields

$$\vartheta = 9.06 \sin\left(\frac{2\pi}{T}t + 251°\right) + 0{,}98 \sin\left(\frac{4\pi}{T}t + 80°\right),$$

for the surface temperature in pine forest,

$$\vartheta = 7.40 \sin\left(\frac{2\pi}{T}t + 244°\right) + 0{,}90 \sin\left(\frac{4\pi}{T}t + 54°\right),$$

and in beech forests

$$\vartheta = 7.10 \sin\left(\frac{2\pi}{T}t + 244°\right) + 0{,}48 \sin\left(\frac{4\pi}{T}t + 64°\right).$$

The influence of amplitude differences at the surface on the temperature range of the first harmonic becomes, at the depth z at time t, according to equation (1).

$$\Delta\vartheta = e^{-\sqrt{\frac{\pi}{Tm}}z} \cos\left(\frac{2\pi}{T}t - \sqrt{\frac{\pi}{Tm}}\,z\right)\Delta\vartheta_1$$

At a depth of 150 cm therefore a change of the amplitude of the first harmonic of the annual range at the surface with ± 1,0° C becomes

$$\Delta\vartheta = \pm 0.65 \cos\left(\frac{2\pi}{T}t - \sqrt{\frac{\pi}{Tm}}\,150\right)$$

which is still detectable.

Amplitude differences of the same magnitude in the harmonics have a smaller effect on the temperature at 1,5 m depth. It can easily be seen that the biggest differences are to be expected in summer and in winter.

Local variations of the mean annual temperature.

In flat areas the mean annual temperatures at the observation depth differ by up to 1.5° C, depending on the vegetation and the moisture at the surface (Keränen 1929). This value is only obtained in the case of extreme variations in the vegetation as, for instance, with a change from a dense forest to an open field.

Generally, the mean temperatures within an area vary by considerably less than this.

DISCUSSION OF POSSIBLE CORRECTIONS TO ELIMINATE SURFACE EFFECTS

That part of the temperature variation due to extraneous surface influences could be eliminated if it was possible to determine the annual mean temperature at each observation point. In principle, all that is required to determine this is a series of readings made at various depths or at various times over a whole year. It should then be possible, by assuming values for the diffusivities, to compute the amplitude of the variations at individual stations.

If the method of taking temperatures at various depths is to be used, it is necessary to make observations at depths of less than 1.5 m.

However, temperature variations in the soil near the surface, do not follow exactly the relationship given by the heat conduction equation. Mass exchange processes such as percolating rainwater disturb the range of temperatures given by this equation. In addition the thermal diffusivity, depends on the moisture content and therefore varies with time. For these reasons it is not possible to determine a satisfactory mean annual temperature from simultaneous observations taken at various depths.

A better result can be obtained if the mean annual temperature is computed from several observations made at different times at a depth of 1.5 m. The accuracy of the annual mean temperature determined increases with the number of observations. In practice there is generally only one repeated measurement. The mean annual temperature can then be computed if it is assumed that the phase of the oscillation is known. This assumption is justified as the differences in phase at the individual observation points in any area are small. The error in the mean annual temperature is then mainly caused by the deviation of the measured temperature from the first harmonic. However, it should be noted that this error does not become effective to be full extent, because all stations show it in the same direction. This is due to the fact that the annual change of temperature at the observation depth, and also its higher harmonics, originate from the change in weather condition during a year. Thus a cold period of several weeks in summer causes the temperatures at the observation depth to lie below the sine shaped curve of the first harmonic. This influence acts in the same direction at each measuring point. Of course the magnitude of the deviation at the individual stations differs, depending on the nature of the surface and the thermal diffusivity of the outcropping soil.

The total effect of all the factors which influence the observation and which cannot be determined by repeated observations, depends on the variation of the surface conditions in the measuring area. In the case of uniform vegetation (e.g. a meadow or a field) it is not necessary to determine the annual mean temperature. It is only necessary to measure the variations of temperature at several base stations spaced over the area during the measuring period. These variations can then be used to correct the observed temperatures so that they are all valid for one specific time. The variations caused by local differences in thermal diffusivity of the soil may then be about ± 0,5° C.

HEATING AT THE OBSERVATION DEPTH CAUSED BY HEAT FLOW FROM DEPTH

If a heat flow of density q rises from depth to the surface of the earth, the mean temperature at the surface is slightly higher than the value which would be observed if the heating were due solely to the radiation from the sun. This temperature increase is dependent on the heat transfer conditions at the surface of the earth. The following relation holds for a small q and a heat reservoir above the surface, large compared with q

$$\vartheta_2^{\times} - \vartheta_1^{\times} = q/\alpha, \text{ in which}$$

$\vartheta_1^{\times}$ = mean temperature at the surface without a heat flow from depth

$\vartheta_2^{\times}$ = mean temperature at the surface of the earth with a heat flow from depth

α = surface conductivity (i.e. the density of heat flow normally outwards through the surface divided by the temperature difference between the surface of the body and the surrounding medium) (cal cm^{-2} sec^{-1} $^\circ \text{C}^{-1}$).

If the determination of the temperature is not carried out at the surface of the earth, but in a depth z, then the Fourier equation applies:

$$q = -k \text{ grad } \vartheta, \text{ where}$$

k = thermal conductivity of the soil (cal cm^{-1} sec^{-1} $^\circ \text{C}^{-1}$).

If the heat flows vertically to the surface of the earth, then

$$q = k \frac{\vartheta_3^{\times} - \vartheta_2^{\times}}{z}$$

$\vartheta_2^{\times}$ = temperature at the surface
$\vartheta_3^{\times}$ = temperature in the depth z

The combination of both equations gives the mean annual temperature as a function of the depth.

$$\vartheta_3^{\times} = \vartheta_1^{\times} + \frac{q}{\alpha}\left(1 + \frac{\alpha z}{k}\right)$$

Equation (1) now becomes

$$\vartheta(z, t) = \vartheta_1^{\times} + \frac{q}{\alpha}\left(1 + \frac{\alpha z}{k}\right) + \sum_{n=1}^{n=\infty} \vartheta^{=}_{n} e^{-\sqrt{\frac{n\omega}{2m}}\, z} \cos\left(n\,\omega\,t - \sqrt{\frac{n\,\omega}{2m}}\, z - \gamma_n\right) \quad (2)$$

Birch (1955) showed that the natural heat flow does not in general exceed $1.75 \cdot 10^{-6}$ cal cm^{-2} sec.$^{-1}$.[1]

For the heat conductivity of the soil a mean value of $k = 3 \cdot 10^{-3}$ cal. cm^{-1} sec^{-1} °C^{-1} will be assumed. According to M. Jakob (1926) the surface conductivity has a value of about $2.0 \cdot 10^{-4}$ cal cm^{-2} sec.$^{-1}$ °C^{-1} for a rough surface with slight air movements.

This value is rather uncertain, and in nature it undergoes considerable local and temporal variations. However, in these investigations, this fact does not matter so much, as the influence of the heat transfer conditions at the surface of the earth is not so important.

For $k = 3.10^{-3}$ cal cm^{-1} sec^{-1} °C^{-1} and
$q = 1.75.10^{-6}$ cal cm^{-2} sec^{-1}

the heating at a depth of 1.5 m is

$\vartheta_3^{\times} - \vartheta_1^{\times} = 9.6.10^{-2}\ {}^{\circ}C$ if $\alpha = 2.10^{-4}$ cal cm^{-2} sec^{-1} $^{\circ}C^{-1}$
$\vartheta_3^{\times} - \vartheta_1^{\times} = 8.7.10^{-2}\ {}^{\circ}C$ if $\alpha \to \infty$.

In these calculations we have used fixed values for several constants which in reality undergo local and temporal variations (e.g. surface conductivity, and heat conductivity of the soil). But even if the full range of values compatible with conditions at and near the surface of the earth is considered, a heat flow of $q = 1.75 \cdot 10^{-6}$ cal cm^{-2} sec^{-1} will cause an increase of less than about 0.1° C at a depth of 1.5 m. It is not possible to separate this increase of 0.1° C from the temperature variations caused by varying surface conditions in the area surveyed. Thus a heat flow ten times the normal is required to produce a detectable temperature anomaly of about 1° C.

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[1] The solar constant involving the energy coming from the sun is 20 000 times larger.

Effects of Subsurface Conditions

Influence of the differences in conductivity of deeper rocks.

The maximum range of thermal conductivities of the deeper rocks is from about 3.10^{3} cal cm^{1} sec^{-1} $°C^{-1}$ for layered (and therefore badly conducting) clay and marl (Reich 1943) to 15.10^{3} cal cm^{-1} sec^{-1} $°C^{1}$ for massive mineral salt (Guoyod 1946).

These minor differences (c.f. variation in electrical conductivity) lead to anomalies which are, at the maximum, only of the same order of magnitude as the total temperature increase caused by natural heat flow (p. 247).

Such temperature variations, however, cannot be separated from the local variations due to changing external influences (e.g. different vegetation or locally different thermal conductivities of the soil). They are, therefore, not recognizable as being caused by the deeper subsurface. But because in the opinion of various authors (Paul 1935, Jakoski 1950, Nettleton 1940, Heiland 1946) differences in heat conductivity in the subsurface, and particularly in salt domes, can be detected by temperature measurements at depth between one and two meters, we computed a model in which the possible differences in heat conductivity were used. We found that no measurable temperature differences were likely to be produced.

Thus it can be said *it is not possible to identify horsts or salt domes by this method.*

Heating due to the natural decomposition of radioactive rocks.

Radioactive elements occur, for example, in granitic rocks. Let us assume that such a rock complex has a very large horizontal extension compared with its thickness.

The heat generated during the decomposition of the radioactive elements then rises, wholly or in part, in a vertical direction to the surface. In addition to this we have the natural heat flow into the bottom of the rock complex.

If all or part of the heat generated is not transferred to the surface the rock reheats itself and we have $\partial\vartheta/\partial t \neq O$.

If the temperature at every point remains constant, $\partial\vartheta/\partial t = 0$ and all the heat generated is transferred to the surface.

p = uranium content of the rock $\dfrac{\text{gram uranium}}{\text{gram rock}}$

ε = heat production per gram uranium plus metabolon (cal g^{-1} sec^{-1})

r = thorium content of the rock $\dfrac{\text{gram thorium}}{\text{gram rock}}$

δ = heat production per gram thorium plus metabolon

c specific heat of the rock (cal g^{-1} °C^{-1})
ρ = density of the rock
k = thermal conductivity of the rock
l = thickness of the rock complex (cm)

The heat conductance equation is best be written in the form

$$\frac{\partial\vartheta}{\partial t} = \frac{(p\varepsilon + r\delta)}{c} + \frac{k}{\rho c}\,\frac{\partial^2\vartheta}{\partial z^2}$$

In the simplest condition, that is when all the heat flowing into and generated in the complex is transferred to the surface, so that $\partial\vartheta/\partial t = 0$, the solution of the equation is

$$\vartheta = -\frac{(p.\varepsilon + r\delta)\,\rho}{k}\,\frac{z^2}{2} + \frac{q_n + (p.\varepsilon + r\delta)\,\rho l}{k}\,z + \frac{(p.\varepsilon + r\delta)\,\rho l + q_n}{\alpha} + \vartheta_1^{\times}$$

The heating due to the enrichment of radioactive elements is

$$\Delta\vartheta = \frac{(p.\varepsilon + r\delta)\,\rho l}{\alpha} + \frac{(p.\varepsilon + r\delta)\,\rho l}{k}\,z - \frac{(p.\varepsilon + r\delta)\,\rho}{k}\,\frac{z^2}{2}$$

In evaluating this term for possible enrichments with uranium and thorium in thick rock massifs the following values were assumed:

$$p = 10\,.\,10^{-6}\,\frac{\text{g uranium}}{\text{g rock}}$$
$$\varepsilon = 2.5\,.\,10^{-8}\ \text{cal g}^{-1}\ \text{sec}^{-1}$$
$$r = 2.0\,.\,10^{-5}\,\frac{\text{g thorium}}{\text{g rock}}$$
$$\delta = 0.68\,.\,10^{-8}\ \text{cal g}^{-1}\ \text{sec}^{-1}.$$
$$\rho = 2.8\ \text{g cm}^{-3}$$
$$k = 5\,.\,10^{-3}\ \text{cal sec}^{-1}\ \text{cm}^{-1}\ {}^{\circ}\text{C}^{-1}$$
$$l = 3\,.\,10^{5}\ \text{cm}$$
$$\alpha = 2\,.\,10^{-4}\ \text{cal cm}^{-2}\ \text{sec}^{-1}\ {}^{\circ}\text{C}^{-1}$$

For $z = 150$ cm we get a temperature increase of $1.13\,.\,10^{-2}$ °C.

Thus it is impossible to prove concentrations of radioactive matter in the subsurface by temperature measurements at shallow depths.

Heat transport by convection.

The transport of heat by convection can be considerably larger than that which is possible by pure heat conduction through the rocks. This is most obvious in areas of recent volcanic activity where great quantities of heated material emerge at the surface or penetrate the upper layers.

In thermally undisturbed regions also, water percolating down from the surface is heated. If subsequently this heated water rises through fissures and re-enters the soil it gives up heat gained in the process. The result is that locally the annual mean temperature is raised. Bouwhuysen 1934 considers this process in interpreting his observations.

We will now compute for a simple model the area at a depth z over which water must pass in order to raise its temperature by a certain amount (fig. 3). For the purpose of determining this temperature increase, the periodic temperature variations may be disregarded, and only the average mean annual temperatures need be considered. It is assumed that under uniform conditions the water runs from all sides to a centre point from which it can then rise and re-enter the soil. We will calculate for a disc shaped water bearing layer at a depth z the radius required for a certain increase in temperature with a given water delivery rate at the centre. It is assumed that the water at the perimeter of the disc is at the mean annual temperature.

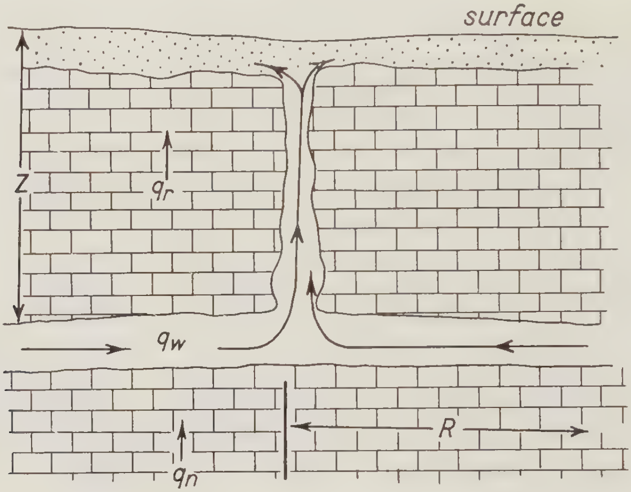

Fig. 3. Heating of water rising from depth to the surface

As the natural heat flow from depth passes upwards through the disc shaped layer, some of it is absorbed by the water in the layer causing the temperature at depth z to rise, the remainder passes upwards to the surface. The percentage of the natural heat flow absorbed by the water is greatest where this water is coldest. It is assumed that at every point in the layer there is no variation of temperature with time ($\partial\vartheta/\partial t = 0$).

The following notation will be used:

ϑ_1 = Temperature directly below the layer
ϑ_2 = temperature within the layer
ϑ_3 = temperature directly above the layer
ϑ_0 = average temperature at the surface
q_n = density of natural heat flow of the earth (cal cm^{-2} sec^{-1})

q_w = the portion of the natural heat flow absorbed by the heating of the water
q_r = the portion of the natural heat flow rising to the surface
α = surface conductivity between water and rock
k = heat conductivity of the rock existing on the top of the layer
z = depth of the layer
W = quantity of the flowing water (cm^3 sec^{-1})
r = radial distance
C = specific heat of water (cal cm^{-3} °C^{-1})
Θ_2 = temperature of the water in the centre
R = radius of the disc

The following relations now hold:

$$\begin{aligned} q_n &= q_r + q_w \\ q_n &= \alpha\,(\vartheta_1 - \vartheta_2) \\ q_r &= \alpha\,(\vartheta_2 - \vartheta_3) \\ q_r &= k\,(\vartheta_3 - \vartheta_0)\,/z \end{aligned}$$

Also considering the heating of the water which results from the absorbed portion of the heat flow, we have

$$q_w = -\frac{W \cdot C}{2\,\pi\,r}\,\frac{d\vartheta_2}{dr}$$

At the same time we find by combining the first four equations

$$q_w = q_n - \frac{\alpha k\,(\vartheta_2 - \vartheta_0)}{\alpha\,z + k}$$

Equating the right hand sides of the last two equations, intergrating the resulting differential equation and substituting the proper limits, we finally obtain

$$\frac{R^2}{W \cdot C} = \frac{(z + k/\alpha)}{\pi\,k}\;ln\;\frac{q_n}{q_n - \dfrac{k}{z + k/\alpha}\,(\Theta_2 - \vartheta_0)}$$

In Fig. 4 the variation of this function with depth is shown for various increases in temperature. The values of the constants used in the calculation are

q_n = 1.75 . 10^{-6} cal cm^{-2} sec^{-1}
k = 5 . 10^{-3} cal cm^{-1} sec^{-1} ° C^{-1}
α = 5 . 10^{-2} cal cm^{-2} sec^{-1} ° C^{-1}

If the computed value of the radius as given in fig. 4 is multiplied by 10^6 π $W.c.$ the result gives the area (in cm^2) of the disc required to give the temperature increase.

The area in this case is a maximum value and is reached only if the water

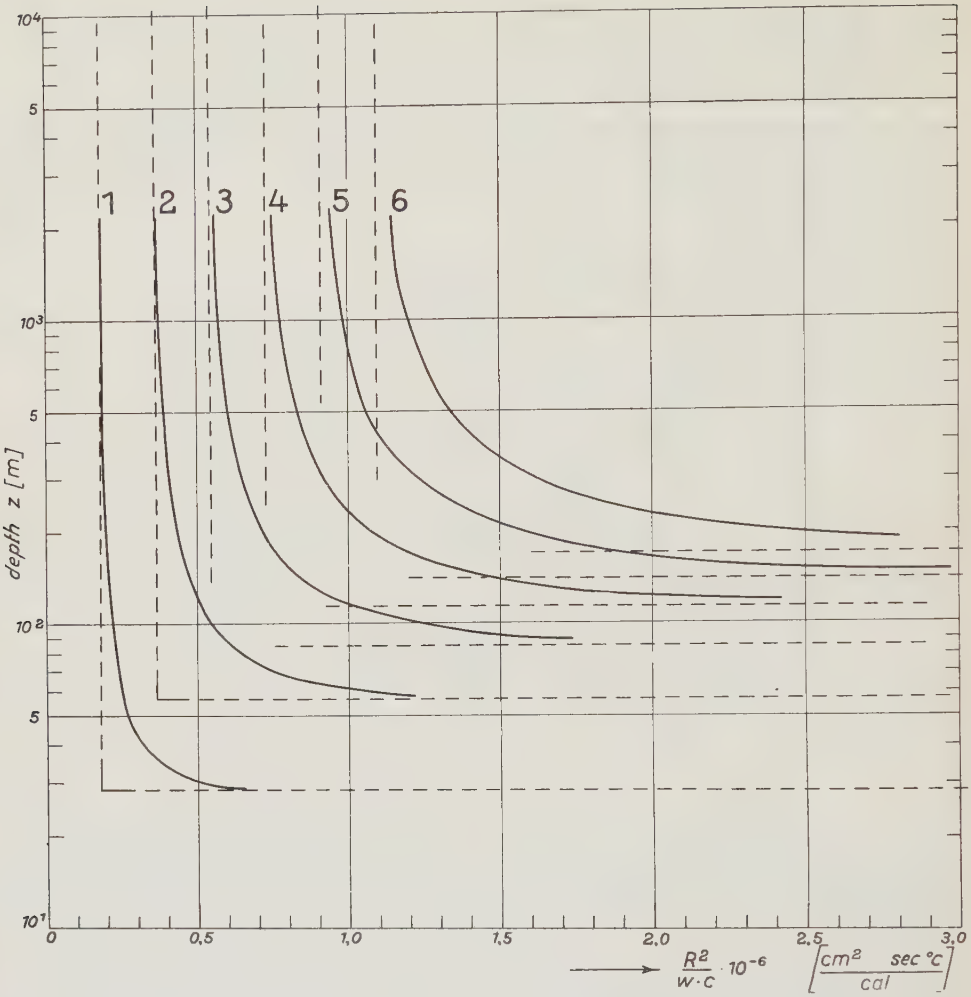

Fig. 4. Heat catchment area required as a function of depth for various temperature increases

flows through the disc for a very long time. Before this, conditions cannot be regarded as stationary, and as long as the steady state is not reached the water gains additional heat from the cooling of the surrounding rocks.

The computations on a model were carried out after some observations had been made near a karst fissure. From geological and hydrological investigations a place was known, in the Neckar valley near Kiebingen, where the water rises along a fissure from a depth of about 100-150 m. to join the groundwater stream below the surface. The groundwater level in this area lies at a depth of about 4-6 m. We wished to find out if it was possible to use the

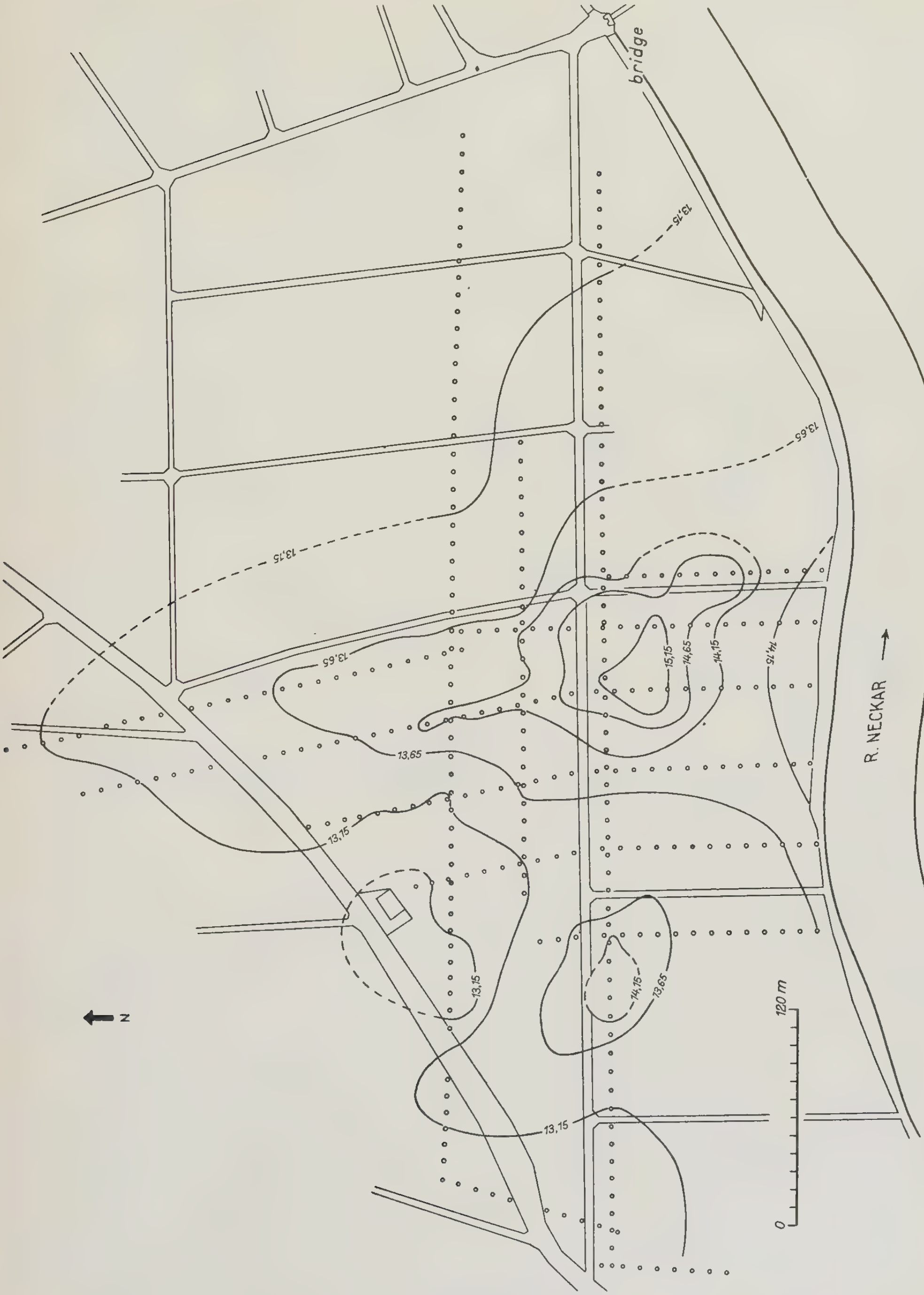

Fig. 5. Neckar Aue near Kiebingen, temperatures at a depth of 1.5 m, referred to the 16th October 1953

method described above to locate accurately those places under which the water rises from the depth. (fig. 5). The results indicate clearly an increase in temperature above water bearing fissure. The position of the survey was particularly favourable, measurements being made over a horizontal surface covered by a completely homogeneous overgrowth of grass. Because of this the corrected temperatures beyond the anomaly, reduced to a single point in time, vary by only about 0.2° C about the mean value.

As the shape of the anomaly curve was known accurately it was possible to compute the quantity of heat which had to be supplied from depth per unit of time, in order to keep the temperature stable. The quantity calculated was $14 \cdot 10^3$ cal sec^{-1}.

By temperature measurements made directly in the groundwater at the centre of the anomaly it was established that the water flows in from depht with a temperature exceeding the normal mean annual temperature by about 3-4° C. With the known specific heat of water we can compute that the quantity of water, required to transport this quantity of heat, is 240 litres per minute. This value gives a first approximation to the yield of this water source.

In addition we computed, with the help of the above mentioned model, the area from which the water must flow at a depth of 125 meters so that, for the delivery rate found, the temperature will increase by 3.5° C. We found this area to be 1.5 km^2.

From the measurements made near Kiebingen the following conclusions may be drawn.

In principal it is possible to discover, by temperature measurements near the surface, fissures in the subsurface along which water rises from great depth and joins the groundwater stream below the surface.

Thermally these conditions are similar to those found when heat is transported by steam and gas media along tilted and porous zones.

In cooperation with the Prakla Company, we had an opportunity of applying this method in Southern Italy during a search for natural steam occurrences. These investigations were carried out at the request of the Italian firm of Safen. We were able to find occurrences which were only partly indicated by Fumaroles. The area and shape of the temperature anomaly gives some indication of the dip and strike of the steam bearing zone. The anomaly shown in Fig. 6 represents a very small steam occurrence which was completely unknown before the survey began. From the observations made at the individual stations it was also possible to compute approximately the quantity of heat which is transferred to the surface. In this case about 55 000 cal per second are supplied from depth. This value may give a rough indication of the extent to which individual steam occurrences regenerate themselves.

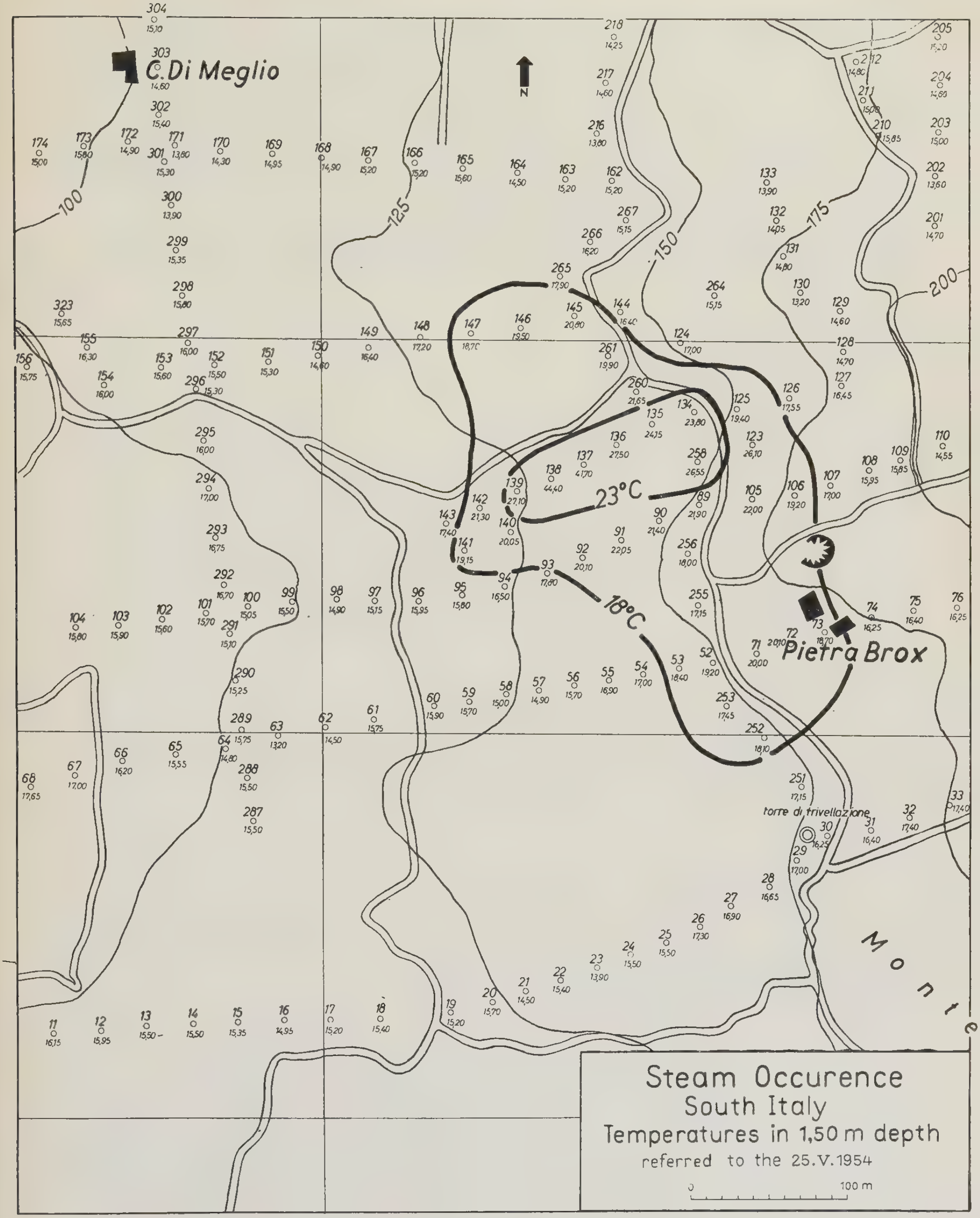

Fig. 6. Steam occurrence South Italy, temperatures at a depth of 1.5 m, referred to the 25th May 1954

In regions such as this where the heating effect is large, it is better to present the results, not as temperatures reduced to a certain depth and time, but as rates of heat flow q. The advantages of this method of presentation is that the heat flow q is independant of the season, and it is then possible to compare observations from points at different depths. During a survey made in Iceland last year, it was found that reasonable numerical values result if the heat flow q at each station is given in cal $\mathrm{sec}^{-1}\,\mathrm{m}^{-2}$.

If the condensation of the steam in the subsurface takes place on a widely extended horizontal face, one gets the following relations:

$$\vartheta_k = \bar{\vartheta} + \frac{q\,(z_k - z)}{k_1}$$

$$\bar{\vartheta} = \vartheta_1 + \frac{q}{\alpha}\left(1 + \frac{\alpha z}{k_2}\right)$$

$$q = M\,C_g\,(\vartheta_g - \vartheta_k) + MQ_k$$

It follows that:

$$z_k = z + k_1 \left\{ \frac{\vartheta_k - \vartheta_1}{MC_g(\vartheta_g - \vartheta_k) + MQ_k} - \frac{1}{\alpha}\left(1 + \frac{\alpha z}{k_2}\right) \right\}$$

In these equations the following notation has been used

ϑ_k = boiling point of the water
z_k = depth of the boiling process
ϑ_1 = mean temperature at the surface
$\bar{\vartheta}$ = mean temperature in the measuring depth
z = measuring depth
q = density of heat flow to the surface of the earth
k_1 = thermal conductivity of the rock
k_2 = thermal conductivity of the soil
α = surface conductivity at the ground surface
c_g = specific heat of steam (cal $\mathrm{gr}^{-1}\,{}^\circ C^{-1}$)
M = amount of steam in gram which is being condensed per cm^2 and sec
ϑ_g = temperature of the steam
Q_k = heat of condensation

Processes taking place at point and line heat sources can be treated mathematically by the same method, and known solutions from potential theory can be applied. However, as the assumptions made for the known solutions are not completely satisfied, and as it is not possible to give a heat conductivity for the air which takes into account the convection which occurs in nature, we will not discuss these cases.

Anomalies which vary with time.

As a final example of the thermal method a temperature anomaly which varies with time will be discussed. It occurs when channel or river water percolates through permeable dams. Fig. 7. shows the graphology of the annual temperature variations in the soil at a depth of 1,5 metres, and in a North German canal. A comparison of the two graphs shows that:

1. The temparatures of canal water in North Germany may vary within one year from 0° C to approximately 23° C, while the temperature range in the soil is only from 3° C to 16° C.

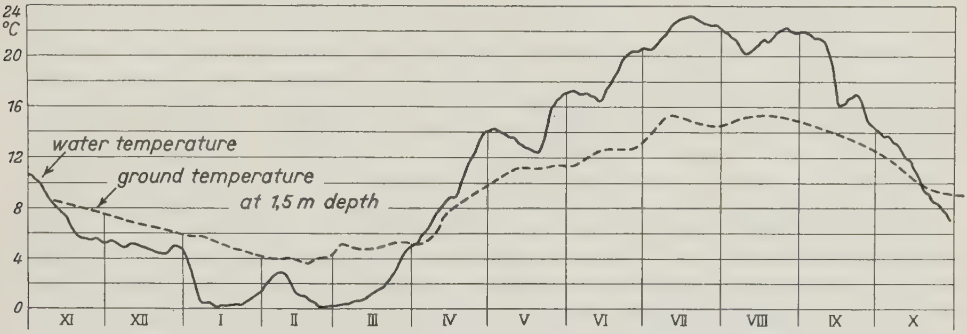

Fig. 7. Temperature ranges at a depth of 1.5 m in the soil, and in the water of a canal

2. The temperature of the canal water varies with the weather, and this variation may be quite considerable over periods of only a few days, while the soil temperatures at the observation depth follow a relatively smooth curve.

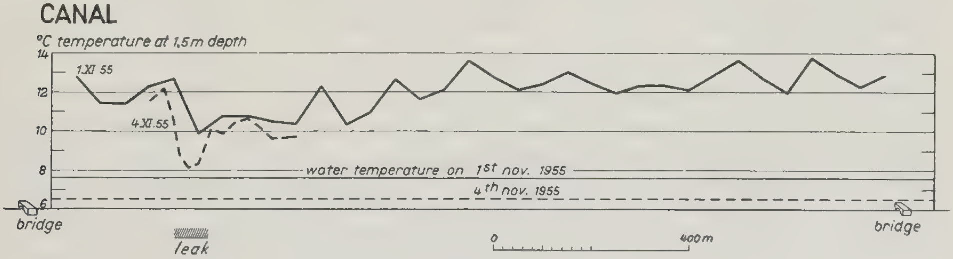

Fig. 8. Temperature measured along a canal bank

If water from the canal enters the soil at certain points such places are readily detectable because of the large amplitudes of their temperature variation curves. Moreover at stations very near the canal rapid temperature variations can be observed.

Fig. 8 shows the results of observations made alongside a canal at about

3 metres from the bank. A distinct minimum can be seen. As the canal water was colder than the normal soil temperature at the observation depth, this minimum indicated a permeable place. After three days we repeated the measurements with a smaller spacing between the observation stations, again the minimum was observed and its position could be fixed with greater accuracy. The station with the lowest temperature also shows the most rapid response to changes in the temperature of the canal water. This low temperature together with the rapid variations of temperature can only be explained by percolating canal water. At greater distances from the canal an interpretation of the temperatures becomes more complicated as the flow velocity of the groundwater is usually very small. In North Germany it is often less than 1 metre per day, so that the temperature range during the previous months must be considered in interpreting the results. Investigations into the possible applications of this method to such cases are still in progress.

ACKNOWLEDGEMENTS

I wish to express my thanks to Herrn Dir. Dr. Closs, Head of the Department Geophysics of the Amt für Bodenforschung, as well as to Herrn Paul, Director of the Gewerkschaft Brunhilde, Hannover for their valuable suggestions and esteemed assistance. Signore Director Dr. Minucci has been so kind to allow parts of the measuring results made for the Italian firm "SAFEN" to be represented in fig. 6.

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TECHNIQUE NOUVELLE DE MODÈLES RÉDUITS POUR LA PROSPECTION ÉLECTRIQUE

PAR

L. CAGNIARD *) ET R. N. NEALE *)

Abstract

The use of small scale models in the interpretation of results of electric prospecting involves two majors difficulties: (1) the dimensions of the models and of the tanks in which the experiment is performed must be of unwieldy large sizes if one wants to be quite free from side effects; (2) the precise geometrical relation, in respect to the model, of the successive points where the interesting data are measured, requires an intricate installation, and is costly in both time and money.

The technique which is described in this paper eliminates these difficulties as well as some others. The surface of the ground is represented by the lower face of a thick horizontal plate of plexiglas which is laid at the surface of the liquid filling the tank. This plate is pierced by a great number of small holes whose coordinates have been measured initially with the necessary precision. The electrodes are then introduced into these holes without creating any perturbation in the distribution of the lines of current flow. A solution of copper sulphate is used as the liquid in conjunction with copper electrodes. In this way, a D.C. excitation is possible, combining precision with convenience.

Utilité des Modèles Réduits en Prospection Électrique

La prospection électrique, par courants continus ou de très basse fréquence, présente ceci de séduisant qu'elle apporte d'emblée des résultats évocateurs, des graphiques très ,,parlants'', du moins si l'on s'en tient au point de vue purement qualitatif. Au seul aspect des cartes, des profils de potentiel ou de résistivités, on découvre souvent l'existence et l'emplacement de filons, de failles, de contacts entre terrains inégalement résistants. Au premier coup d'œil jeté sur un diagramme de sondage électrique, on reconnaît souvent la présence de diverses formations superposées, et l'on se fait une idée sommaire de leurs épaisseurs et de leurs résistivités.

La médaille a son revers. Car le problème mathématique qui consiste à calculer la distribution du courant, dans un sous-sol qu'on se donne a priori, ne peut être intégré pratiquement que dans un tout petit nombre de cas très simples, beaucoup plus simples que ceux qu'on rencontre d'ordinaire en Géo-

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logie. Et c'est pourtant le problème inverse, bien autrement complexe, qui se pose au prospecteur. De sorte que l'infortuné se trouve désarmé quand il lui faut interpréter quantitativement les anomalies observées, quand il veut préciser numériquement un pendage, la puissance d'un filon, l'épaisseur d'une couche ou le rejet d'une faille.

C'est pourquoi les modèles réduits peuvent, ou plutôt pourraient être si précieux. Car ils permettent, ou plutôt permettraient, de suppléer à l'analyse mathématique défaillante. Leur emploi se justifie dans la proposition suivante: si deux structures sont géométriquement semblables, si les rapports des résistivités entre formations homologues sont conservés, et si l'on envisage alors deux points homologues, les potentiels attachés aux points en question se correspondent par proportionnalité.

On pourra se servir des modèles réduits de deux façons. Ou bien, l'on construira arbitrairement des maquettes schématisant un certain nombre de cas géologiques bien typiques, afin de pouvoir mieux deviner à quoi l'on a affaire, le jour où l'on rencontrera, en prospection, une anomalie similaire. Ou bien, quand il s'agira d'interpréter les résultats d'une prospection qu'on vient d'achever, on construira un modèle conforme à ce qu'on suppose de la structure souterraine, pour vérifier si l'anomalie mesurée sur le modèle correspond à peu près à celle qui fut déterminée sur le terrain.

Difficultés d'Ordre Pratique que Présente le Recours aux Modèles Réduits

Une technique d'interprétation, quelle qu'elle soit, ne peut présenter vraiment un intérêt pratique que si sa mise en œuvre est rapide, précise et relativement peu coûteuse. La technique des modèles répond difficilement à ces conditions. Et c'est pour cela qu'elle n'a été employée jusqu'ici que de façon très limitée. C'est pour cela qu'il serait fort exagéré d'affirmer qu'elle est entrée véritablement dans le domaine de l'application industrielle.

Les maquettes, en effet, sont construites sous forme de masses plus ou moins conductrices immergées dans un bac électrolytique. C'est toujours la surface libre de l'électrolyte qui symbolise la surface du sol. Quant aux électrodes, ce sont de petites tiges métalliques en contact avec la surface du liquide. Or il est clair que ces électrodes ne sauraient affleurer exactement la surface libre. Elles s'enfoncent plus ou moins. Par capillarité, un ménisque remonte le long des tiges. Un ,,point de mesure'' ne peut donc être considéré à bon droit comme ponctuel que si une longueur de quelques millimètres est vraiment négligeable à l'échelle des dimensions de la maquette. On se trouve entraîné de ce fait à adopter des maquettes de grandes dimensions, et par conséquent de grandes cuves, contenant plusieurs tonnes d'électrolyte. De là découlent automatiquement toutes sortes de conséquences fâcheuses:

1° — La fabrication de la maquette, sa mise en place dans le bac, sont des opérations difficiles, longues et coûteuses. Il faut vider la cuve, puis la remplir à nouveau, chaque fois qu'on envisage d'apporter quelque modification ou retouche à la maquette.

2° — Quand il s'agit maintenant de localiser les points de mesure sur la surface libre, un nouveau problème assez délicat se pose encore. On utilise habituellement un pont roulant, avec chariot, comportant règles divisées ou tambours micrométriques, pour repérer les coordonnées horizontales des points de mesure.

3° — En réalité, ce n'est même pas par rapport au bâti de la cuve qu'il faut repérer les points de mesure mais bien, en définitive, par rapport à la volumineuse maquette. Et comme on est forcé de mettre en place la maquette dans le bac lui-même, on rencontre encore là de nouvelles difficultés pratiques.

4° — De toute manière, le repérage des coordonnées de chaque point de mesure fait perdre beaucoup de temps. Le report du point sur une feuille de papier également. A moins de recourir au très ingénieux système de repérage imaginé par Utzmann (1954). Système ingénieux, assurément, mais qu'il faut payer de nouvelles complications de l'appareillage.

Nouveau Système de Cuve et ses Avantages

Dès qu'on a une vision claire des inconvénients d'une technique, comme de leur raison fondamentale, les remèdes s'imposent avec évidence. Il faut d'abord atteindre plus de précision dans la définition des points de mesure. Si cette précision est seulement doublée, les dimensions du modèle et du bac peuvent être réduites de moitié, le volume de la maquette et le poids du liquide sont divisés par 8. Mais on désire aussi ne pas avoir à perdre de temps dans le repérage des points de mesure. On veut éviter d'avoir à manoeuvrer des ponts roulants, à actionner des chariots, à lire des tambours micrométriques, à reporter sur une carte les coordonnées lues. Il n'est alors que d'adopter un gabarit rigide pour définir ,,ne varietur'' l'emplacement des points où l'on fera les mesures. La cuve à maquettes ici présentée a été conçue suivant les principes directeurs qu'on vient de dire.

1° — Ce n'est plus désormais la surface libre du liquide qui va symboliser la surface du sol. Ce rôle sera dévolu à la face plane inférieure d'une plaque ,,approximativement'' horizontale de plexiglas. La plaque est épaisse de 15 mm. Elle est longue de 110 cm et large de 65 cm. Elle repose sur quatre supports d'Afcodur (Chlorure de polyvinyle) collés aux quatre angles intérieurs du bac. Ce bac est, lui aussi, d'Afcodur. La face inférieure de la plaque baigne dans l'électrolyte du bac, tandis que la face supérieure est dans l'air.

2° — Dans sa région centrale, la plaque de plexiglas est percée d'une multitude de trous minuscules. Il y en a 12.800, écartés le plus régulièrement possible les uns des autres, de 2,5 mm en comptant d'axe en axe. Ces trous sont répartis à l'intérieur d'un rectangle central de 40 centimètres sur 20. Ce sont, en principe, les seuls points de mesure possibles, si l'on tient à éviter les perturbations dues aux parois du bac. Cependant deux lignes de trous ont été ménagées de surcroît suivant les deux axes de la plaque, et sur toute la longueur de la plaque. Ces trous supplémentaires peuvent servir à adapter des électrodes d'injection et aussi, dans certains cas spéciaux, à effectuer des profils de mesure. Tout cela est visible sur la figure (1), qui représente la plaque de plexiglas vue par en dessous, avec une maquette assujettie à la plaque.

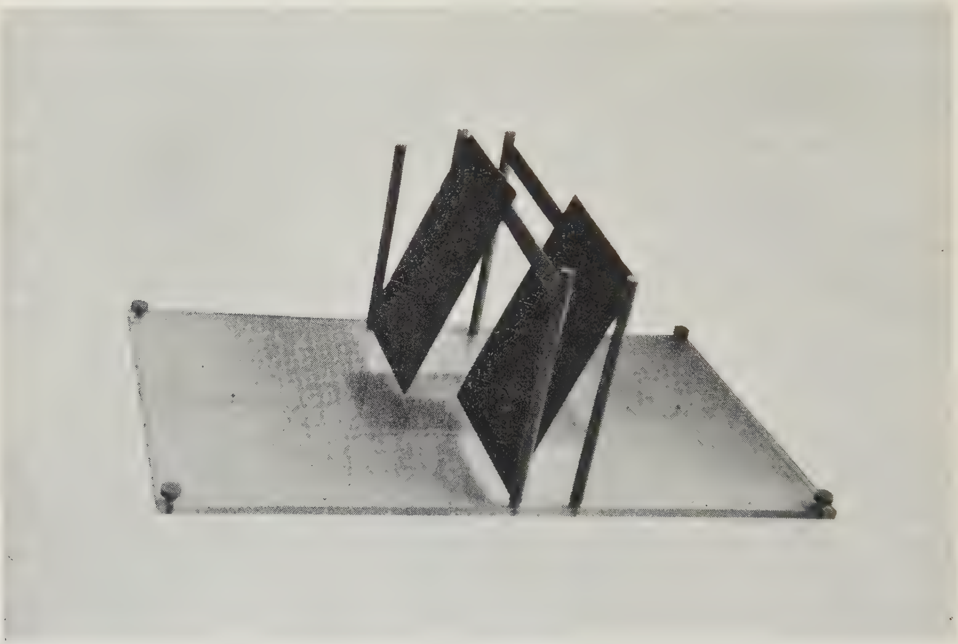

Fig. 1. La plaque de plexiglas vue par-dessous, avec une maquette et deux électrodes d'injection attenantes.

The perspex sheet viewed from below, showing one of the model arrangements and the two current electrodes.

3° — La figure (2) montre la coupe d'un trou. Ce trou s'ouvre sur la face supérieure au diamètre de 1,5 mm, suffisant pour permettre l'introduction d'un fil de cuivre pas trop fin qui servira d'électrode de mesure, ou même d'électrode d'injection. A son débouché inférieur, le diamètre se retrécit à 0,5 mm, pour n'apporter qu'une perturbation infime dans la distribution du courant. Il est clair que tout l'électrolyte du trou se trouve sensiblement équi-

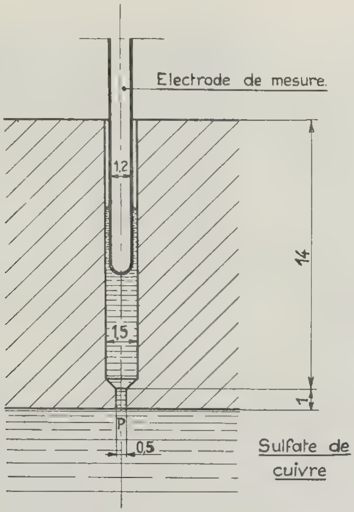

Fig. 2. Coupe d'un trou.
Cross-section of an electrode hole.

potentiel, à un potentiel qui est très approximativement celui du point *P*, sur l'axe du petit trou, au débouché dans le liquide du bac.

Comme on l'a souligné déjà, c'est cette précision dans la définition des points de mesure qui autorise l'emploi de cuves d'un format très réduit. La cuve est représentée sur la figure (3). Ses dimensions sont seulement de 125 × 75 × 60 cm. Cinq cents litres d'électrolyte suffisent à la remplir, au lieu des deux à trois tonnes couramment nécessaires. Dans une cuve si réduite, on réalise pourtant, et très correctement, l'équivalent d'une prospection par ,,carte des potentiels'' où les électrodes d'envoi de courant seraient distantes de 1.600 mètres, et les stations de mesure placées tous les cinq mètres...!

4° — Comme les mesures ne se peuvent faire que dans les trous, l'emplacement des points de mesure est imposé d'avance. On ne peut donc plus, assurément, effectuer de mesures exactement où l'on voudrait. Il n'en résulte pourtant aucun inconvénient, puisque les trous sont extrêmement serrés; une interpolation précise est toujours permise. En somme, les choses ne se passent guère autrement, quand on expérimente sur modèle, que dans le travail de prospection, lorsque les stations à occuper sur le terrain ont été marquées et repérées d'avance par le topographe, au lieu d'être laissées à la faintaisie du prospecteur.

L'avantage, par contre, devient qu'on se trouve libéré radicalement du problème de repérage des points de mesure, puisque ces points sont repérés une fois pour toutes.

Les trous sont, en principe, autant que faire se peut, disposés suivant un

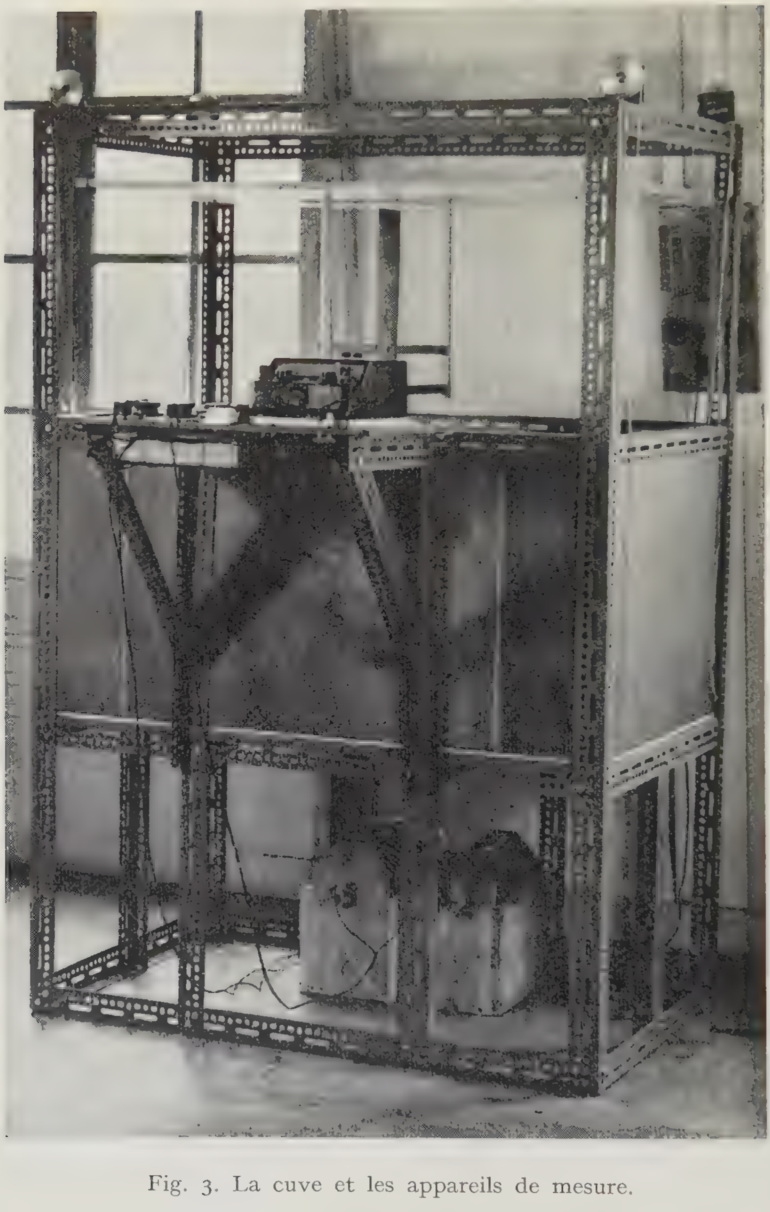

Fig. 3. La cuve et les appareils de mesure.
The tank and the measuring instruments.

carroyage régulier. Suffisamment régulier, en tous cas, pour que des traits de repère, gravés sur la face supérieure du plexiglas, fassent connaître instantanément et sans hésitation le numéro de la ligne et celui de la rangée auxquelles appartient tel ou tel trou.

Si la régularité du carroyage était parfaite, le report des points de mesure pourrait se faire immédiatement sur une feuille de papier quadrillé quelconque, quadrillé en mailles de côté bien entendu arbitraire. Il est avantageux d'adopter un quadrillage nettement plus large que la maille de 2,5 mm qui est celle de la distribution des trous. Car lorsqu'il faudra tracer des lignes équipotentielles, des courbes d'égale résistivité, etc...., il sera bien plus commode de dessiner sur une grande feuille que sur une carte minuscule.

En réalité, la régularité du perçage laisse forcément à désirer. Aussi est-il préférable de reporter les points de mesure sur de véritables ,,cartes muettes'' qui reproduisent avec une minutie et une exactitude rigoureuses la distribution réelle des trous, dans ses plus infimes irrégularités. Ces cartes muettes sont obtenues en autant d'exemplaires qu'on veut par tirages d'un calque original. Ce calque original a été exécuté lui-même en agrandissant photographiquement un cliché de la face inférieure du plexiglas. Les cartes de potentiel représentées par les figures 4, 5 et 6 ont été dessinées sur de telles cartes muettes. Les lignes équipotentielles y apparaissent en surimpression sur le réseau des trous et sur le tracé des lignes qui servent à repérer ces trous, de 10 en 10, et de 5 en 5.

5° — La cuve est petite. Donc les maquettes sont petites. D'où économie de matière première, et de temps passé pour les construire. Une rangée de gros trous, courant sur toute la périphérie de la plaque, visible sur la figure (1), permet d'assujettir commodément la maquette à la plaque. Puisque la maquette est solidaire de la plaque, la question délicate du repérage des points de mesure *par rapport à la maquette* ne se pose même plus. Plus besoin non plus de vider ni de remplir la cuve chaque fois qu'on veut changer de maquette, ou lui apporter la plus minime retouche. Un système de poulies, sur lesquelles s'enroulent des cordes de nylon, et qu'on voit sur la figure (3), permet à une seule personne de soulever, d'ôter, de remettre en place la plaque de plexiglas du même coup que la maquette qu'elle supporte.

6° — D'ordinaire, dans les expériences sur modèles réduits, on se sert de courant alternatif. En raison des phénomènes d'induction, cela ne va pas sans entraîner divers effets parasites, auxquels il faut prendre garde. De toute manière, si l'on veut s'en tenir à la méthode classique d'expérimentation, la réduction des dimensions de la cuve diminue notablement du même coup l'importance relative de ce genre de perturbations.

Mais on a pensé — et on a constaté — qu'il est tout de même bien plus simple encore de renoncer une bonne fois au courant alternatif, et d'employer du courant continu. On utilise alors, comme électrolyte, une solution assez concentrée de sulfate de cuivre commercial, solution qu'il n'est jamais besoin de renouveler. On ajoute assez d'acide sulfurique pour dissoudre les produits basiques ou carbonatés toujours présents dans le sulfate du commerce. La solution devient bien limpide, et le demeure indéfiniment.

7° — On se sert de fils de cuivre comme électrodes de mesure. Si l'on se contente de fils bien nettoyés, on constate qu'il subsiste toujours une légère dissymétrie entre les deux électrodes, laquelle se manifeste par une différence de potentiel résiduelle, de l'ordre du millivolt. Il est évident qu'il est bien facile d'éliminer l'effet de cette dissymétrie, en opérant exactement comme on fait sur le terrain, dans la prospection par courant continu. Il suffit en effet de compenser cette différence de potentiel avant de commencer la mesure, en lui opposant, à l'aide d'un potentiomètre, une force électromotrice égale et de sens contraire.

Mais il est assurément bien plus simple encore de faire subir aux fils de cuivre un traitement préalable, consistant tout uniment à traiter leurs extrémités, durant quelques minutes, par une électrolyse en courant alternatif au sein même de l'électrolyte du bac. Il n'est même plus nécessaire de nettoyer les fils au préalable. Avec des fils dont on a décapé ainsi les extrémités, la dissymétrie s'évanouit pour ainsi dire complètement. Il ne subsiste plus qu'un très faible courant résiduel, quand on branche directement le galvanomètre sur les deux électrodes de mesure. Il suffit alors, avant de commencer la mesure, de ramener le spot au zéro de l'échelle en agissant sur la tête de torsion du galvanomètre. Plus simplement encore, on note la déviation initiale du spot, qui sera le nouveau zéro à adopter, au moment de la mesure, pour repérer l'équilibre.

8° — La mesure se fait à l'aide d'un galvanomètre A.O.I.P. à spot lumineux et sensibilités multiples. On distingue bien ce galvanomètre sur la figure (3). Il est posé sur un pupitre, solidaire du bâti de la cuve, à bonne hauteur d'utilisation, au niveau de la plaque de plexiglas.

Exactement comme en prospection, on mesure les différences de potentiel par la méthode d'opposition ou par celle de déviation. Dans l'un et l'autre cas, on se sert d'un petit montage potentiométrique, installé lui aussi sur le pupitre, à gauche du galvanomètre. Le potentiomètre, alimenté par une petite pile, comporte cinq ,,décades" de résistances, 11 fois 1.000 Ω, 11 fois 100 Ω, 11 fois 10 Ω, 11 fois 1 Ω et enfin 11 fois 0,1 Ω.

9° — Les deux batteries d'accumulateurs, de 6 volts chacune, qu'on distingue au-dessous de la cuve, servent à injecter le courant dans l'électrolyte. De petites piles sèches sont d'ailleurs largement suffisantes pour cela, car les courants les plus intenses dont on ait jamais besoin ne dépassent pas quelques dizaines de milliampères.

C'est évidemment lorsqu'on veut construire une carte de potentiels, avec électrodes d'injection très espacées l'une de l'autre, disons de 80 centimètres par exemple, qu'on aime à disposer d'un courant d'une cinquantaine de milliampères pour faire les mesures le plus ,,confortablement" possible. Or dans un tel cas, les électrodes d'injection restent fixes pendant toute la série de mesures. De sorte qu'on peut se permettre, dans le même temps qu'on assujettit la maquette, d'installer à demeure, sous la plaque, deux électrodes d'assez large surface. La connexion de ces électrodes se fait par des fils fins au travers des trous. Pour que ces électrodes fort „volumineuses'' (elles ont en effet quelques millimètres de rayon) puissent être assimilées malgré tout, aussi légitimement que possible, à des électrodes ponctuelles, on peut leur donner la forme d'hémisphères. Les hémisphères en question baignent dans le liquide, et leur face plane est appuyée tout contre la plaque de plexiglas. Deux telles électrodes hémisphériques en place sont visibles sur la figure (1). C'est ainsi qu'avec 12 volts seulement dans le circuit, on obtient les quelques dizaines de milliampères qu'on veut.

Quand on mesure des résistivités apparentes, que les électrodes d'injection sont relativement rapprochées, disons qu'elles sont à 5 centimètres l'une de l'autre, on peut se contenter de courants d'injection infimes, dont l'intensité se chiffre en dizaines ou centaines de microampères tout au plus. Les électrodes d'injection peuvent fort bien, alors, se réduire à de simples fils dont les bouts baignent dans la portion évasée des trous, exactement comme lorsqu'il s'agit d'électrodes de mesure.

10° — Pour terminer cet article, on reproduira, sans commentaires bien superflus, quelques cartes de potentiel qui ont été construites dans la cuve qui vient d'être présentée. La première des cartes (figure 4) est la „carte normale'', celle qu'on obtient quand il n'y a pas de maquette dans la cuve, celle qui sert de test pour vérifier que les parois de la cuve ne perturbent pas la distribution dans la région centrale de la plaque. Avec la figure 5, on a affaire à un filon mince, infiniment résistant, vertical, placé à très peu de chose près à mi-distance des électrodes d'injection, lesquelles sont fort loin l'une et l'autre, respectivement au-dessus et au-dessous des limites de la carte. La maquette correspondante était tout simplement une mince plaquette d'Afcodur. Enfin la figure 6 correspond au cas d'un filon résistant, incliné, recoupé par une faille de rejet horizontal. La maquette qui a servi à cette étude est précisément celle qui est photographiée sur la figure 1.

Une courte remarque terminale, à propos de ces cartes de potentiel, ne sera peut-être pas absolument inutile. Sur le terrain, quand on dresse une carte des potentiels, on adopte pour zéro des potentiels le potentiel du sol à l'infini. Or dans un modèle réduit, il n'y a pas de point à l'infini. En fait, il importe assez peu de rapporter les potentiels à tel ou tel zéro. Cela dit, il vaut tout de même mieux que le zéro adopté dans le travail sur maquette corresponde au zéro dont on se sert sur le terrain. On peut procéder de la manière suivante. Sur l'alignement AB des deux électrodes A et B d'injection, on intercale deux électrodes de mesure m et n, de telle façon que $Am = Bn$. On fait en sorte que la distance Am soit assez courte pour que l'anomalie de distribution du courant, due à la présence de la maquette, soit vraiment

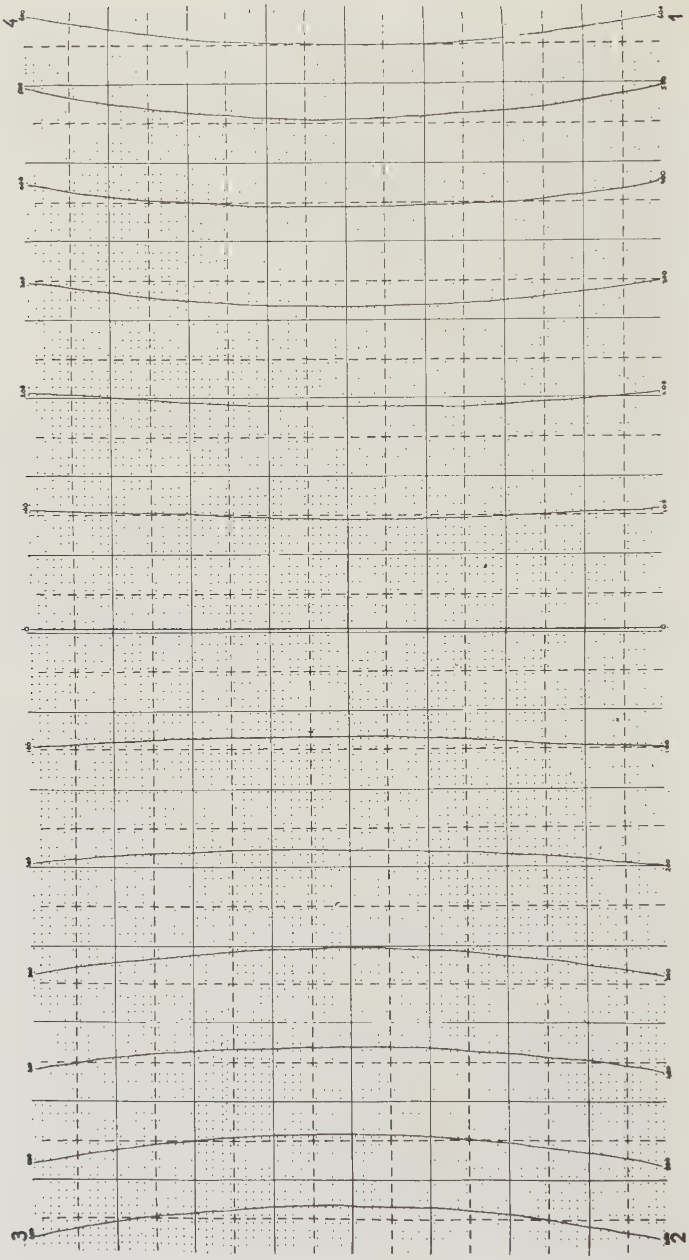

Fig. 4. Carte de potentiels „normale".

„Normal" potential map.

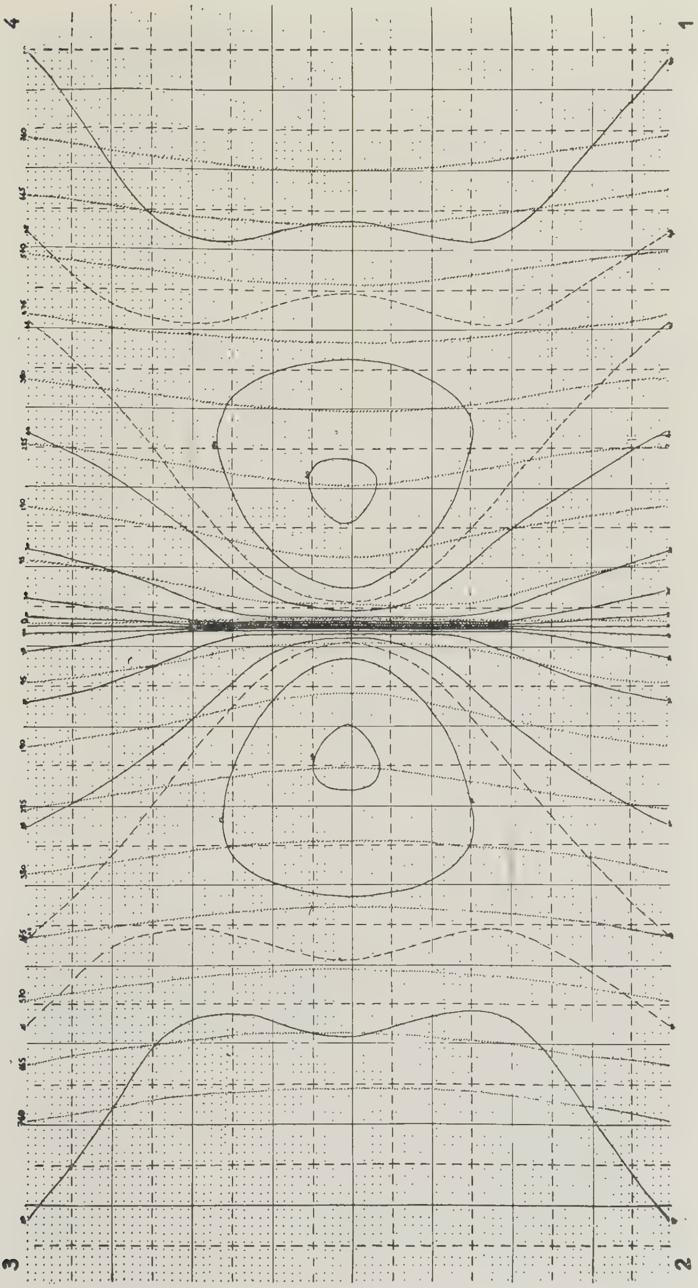

Fig. 5. Filon vertical.
Potential map for a vertical vein.

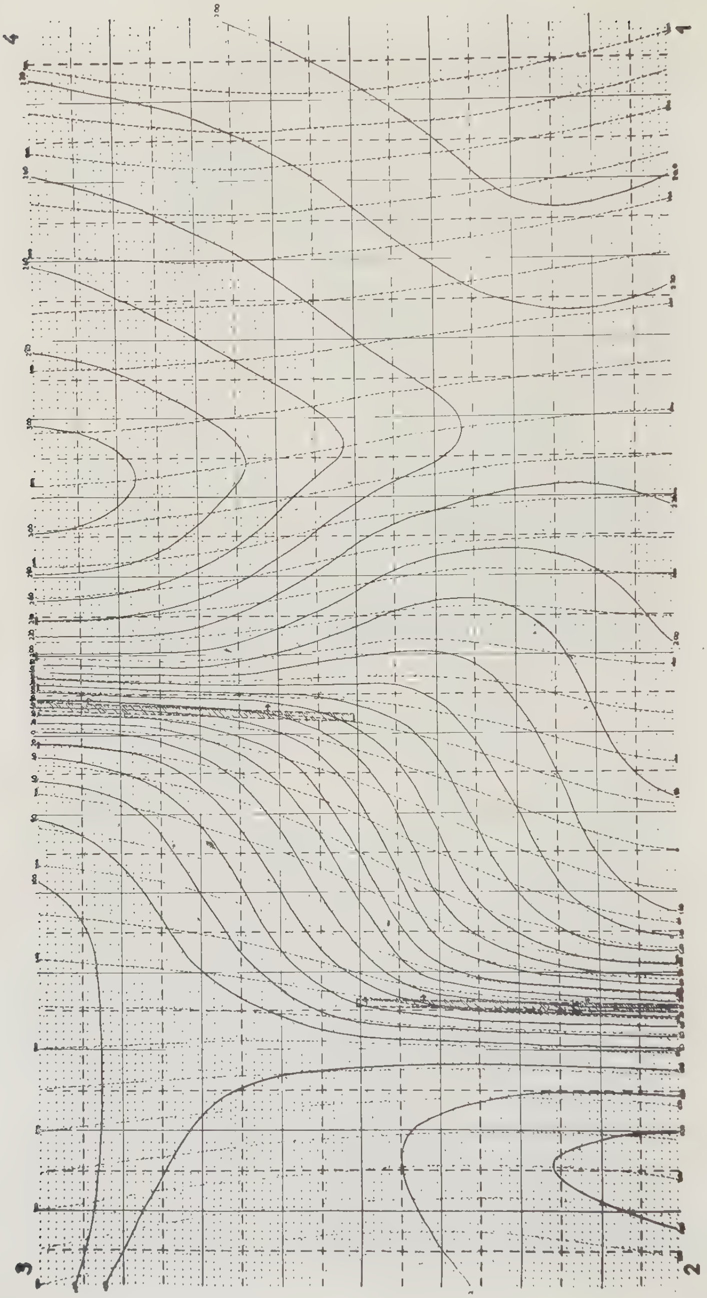

Fig. 6. Filon incliné faillé.

Potential map for a faulted dipping vein.

négligeable en m et n. Mais la distance Am doit rester tout de même assez grande pour éviter les irrégularités éventuelles de la distribution du courant au voisinage trop immédiat des électrodes d'injection. En prenant par exemple $AB = 80$ cm et $Am = Bn = 10$ cm, on réalise un compromis acceptable. On peut alors admettre et convenir qu'un point p de la cuve est au potentiel ,,zéro'' si l'on a:

$$V_m - V_p = V_p - V_n = \frac{V_m - V_n}{2}$$

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ON THE EFFECT OF THE TANK WALL MATERIAL IN GEOELECTRICAL MODEL EXPERIMENTS

BY

W. GOUDSWAARD *)

Abstract

The effect of the composition of the tank walls on apparent resistivity determinations made in model experiments has been investigated for the two extreme cases of an insulating and a perfectly conducting tank wall. The resulting errors have been determined both by calculation and by experiment.

Experiments are described which demonstrate that the magnitude of the effect can be considerably reduced by specially constructed tank walls.

Introduction

The electrical model used consisted of a perspex tank filled with NaCl solution, which can be considered as a completely homogeneous model material.

The apparent resistivity ρ_a was determined along a profile perpendicular to the long side walls of the tank using a Wenner electrode arrangement with fixed electrode spacing. The measurements were repeated using different tank wall materials in an attempt to find the one which had the least effect on the apparent resistivity determination.

Two points regarding the experimental conditions should be noted: Firstly, alternating current was used throughout the measurements, because direct current, as normally used in fieldwork, leads to difficulties due to polarization effects. Secondly, the electrodes are not point sources. The electrodes used were pointed copper nails 2 m.m. wide inserted to a depth of 2 to 5 m.m. below the surface to prevent the electrode—liquid contact breaking whenever the liquid surface oscillated slightly.

Although the formulae used in the interpretation of the resistivity data apply only to direct current and point sources, these approximations have been accepted because of the practical advantages.

Experimental Arrangements

The experimental set up used is shown in Figs. 1 and 2. The inner dimensions of the tank were 100 cms long, 60 cms wide and 70 cms deep, the depth of the liquid was 50 cms.

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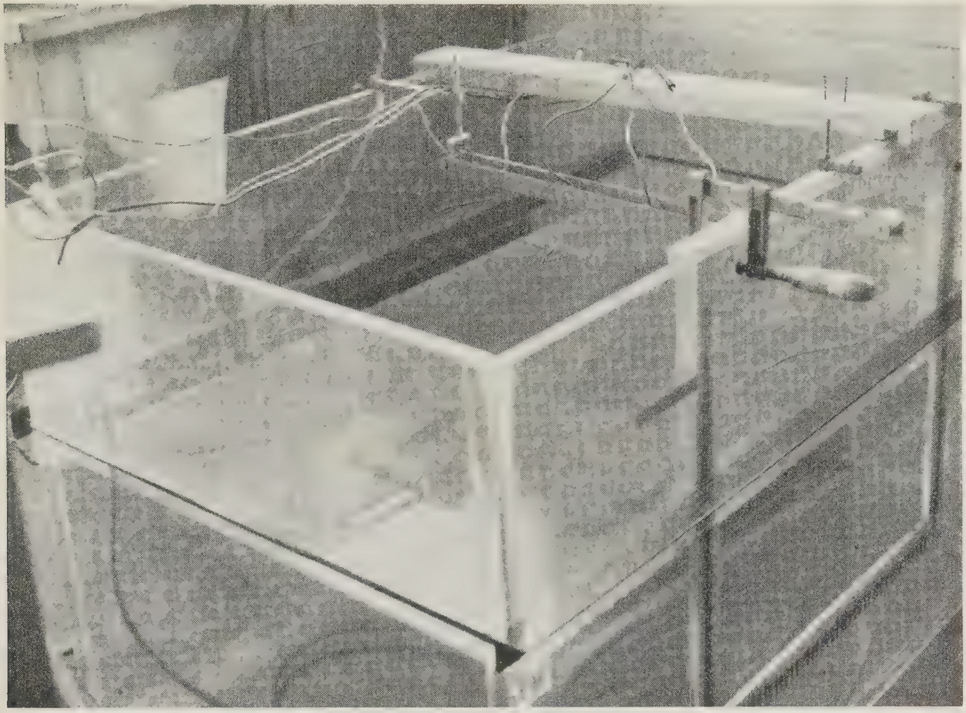

Fig. 1. Model tank arrangement.

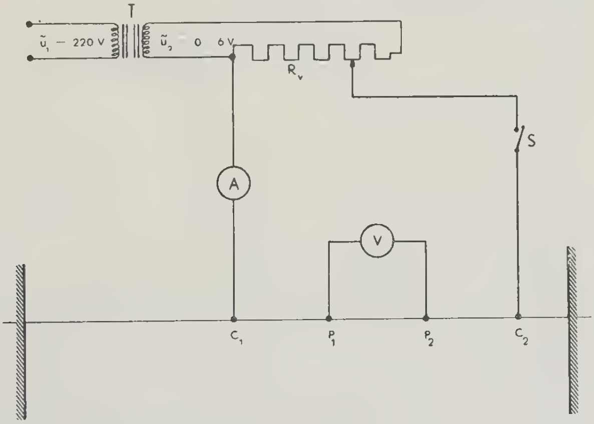

Fig. 2. Schematic diagram of electrode configuration.

Measurements were made along a profile perpendicular to the long side walls of the tank halfway along its length. The electrodes were fixed to small pertinax blocks mounted on a rail, so that the apparent resistivity could be measured as a function of the distance from the centre of the electrode configuration to the wall of the tank. The potential difference ΔV and the current I were then measured using the circuit shown in Fig. 2.

In order to be able to take measurements on a special form of the two layer case a perspex plate was suspended horizontally in the liquid.

THEORY

It has been shown by simple calculations that, under the experimental conditions described, the contributions to the potential difference of the image poles resulting from the short side walls and the bottom of the tank have only a negligible influence on the apparent resistivity. In computing the apparent resistivity as a function of the distance from the centre of the spread to the long side wall, we have therefore only considered the long side walls, and these have been treated as planes of infinite extension. These assumptions permit a simple application of the theory of images. An infinite series of images results. The positions of the image poles nearest to the electrode configuration, C'_1, C'_2, C''_1 and C''_2, are shown in Fig. 3. In the computations only the effects of the image poles shown in this figure have been taken into account. The error in apparent resistivity caused by neglecting the more distant image poles was found to be less than 1%.

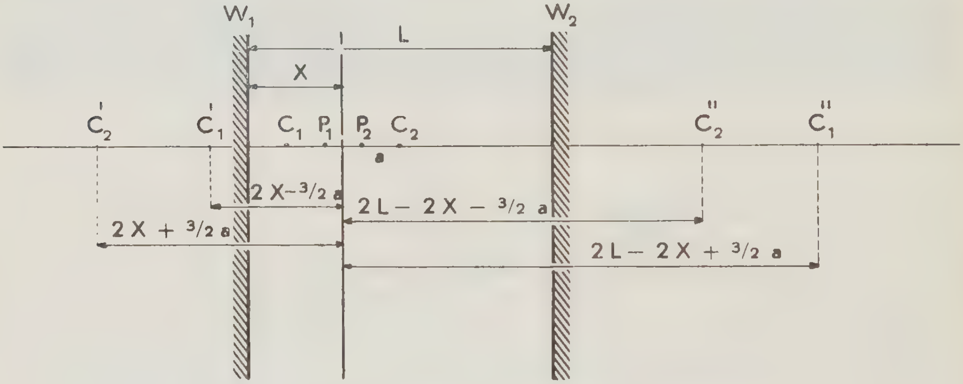

Fig. 3. Position of image poles used in calculation.

For perfectly insulating walls, the reflection coefficient is $K = 1$, so that the strength of the image poles C'_1, and C''_1 is equal in magnitude and sign to the strength of the physical pole C_1; similarly the strengths of C'_2 and C''_2 are equal to that of C_2. For this case, the ratio ρ_a/ρ liquid is represented graphically in Fig. 4 as a function of x (the distance from the centre of the electrode configuration to the side wall), for various values of the electrode separation a.

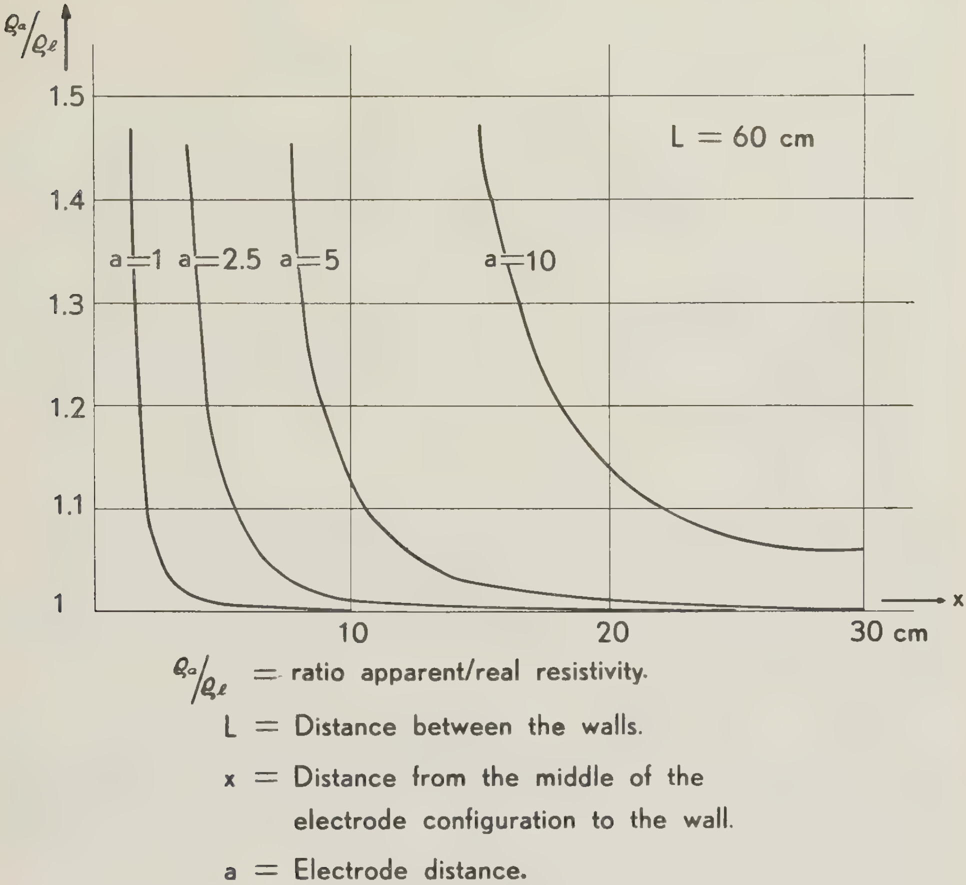

Fig. 4. Theoretical curves of the ratio of apparent resistivity to resistivity of model material as a function of the distance from perspex tank wall.

For perfectly conducting walls, the reflection coefficient is $K = -1$. In this case the strengths of the image poles C'_1 and C''_1 are equal and opposite to that of C_1 and the strengths of the image poles C'_2 and C''_2 are equal and opposite to that of C_2. The resulting theoretical curves of ρ_a/ρ liquid as a function of x are shown in Fig. 6, for two values of a (2.5 and 10 c.m.). It will be noted from the signs of the image poles that the curves for perfectly conducting walls are symmetrical with those for insulating walls with respect to the line ρ_a/ρ liquid $= 1$. This symmetry, of course, would not have existed if it had been necessary to consider the more distant image poles.

RESULTS

Measurements were made of ρ_a/ρ_l as a function of x for two values of a; viz.: $a = 2.5$ and 10 cms, using the following materials for the tank walls

a) Perspex
b) Brass plate
c) Perspex covered by a grid of brass wire.

Before comparing the results obtained with the theoretical curves it should be noted that although the apparent resistivity measured at the centre of the tank with $a = 2.5$ cms should be equal to the absolute value of the resistivity of the NaCl solution (see Fig. 4), it was found that it differed by from 0 to 5% from the value determined using a commercial resistivity measuring instrument (Philiscope). The cause of this discrepancy is not known. As it may be due to polarization phenomena, an attempt was made to minimize the effect of this error on the shape of the curves by keeping the current constant throughout the experiments.

1 *Perspex tank walls.*

Graphs showing the observed values and the theoretical curves are given in Fig. 5. In computing the ratio ρ_a/ρ_l, ρ_l has been taken as the ρ_a measured at the middle of the tank with the smaller electrode spacing. In fact it is the correspondence in shape between the observed and calculated curves, rather than the actual values which is considered to be important.

2. *Brass plate tank walls.*

The tank walls were converted into good conductors by lining them with 1 m.m. brass plate. Fig. 6 shows the observed and calculated curves. The correpondence in shape is reasonable, but not as good as in the case of insulating walls. This may be due to chemical reactions taking place between the NaCl solution and the brass plates.

3. *Perspex tank walls covered with brass wire grid.*

The investigations discussed in this section are purely experimental. It had been suggested that by using a combination of conducting and non-conducting material for the tank walls, their effect on the apparent resistivity measurements could be reduced. Measurements were then made with the perspex tank wall covered with a grid of brass wires. A series of experiments were performed to find the wire gauge mesh which caused the smallest tank wall effect. The best results were obtained using 0.455 cms gauge brass wire and a grid mesh of 2 cms.

In order to investigate the effectiveness of this grid for solutions of different resistivities the measurements were repeated and the graphs drawn for several different concentrations of the NaCl solution. The results, and diagrams showing the position of the outer electrode relative to the nearest grid wire, are given in Figs. 7a and 7b.

It appeared from theoretical considerations that a particular wall construction, which behaves as an insulator with one solution, might be expected

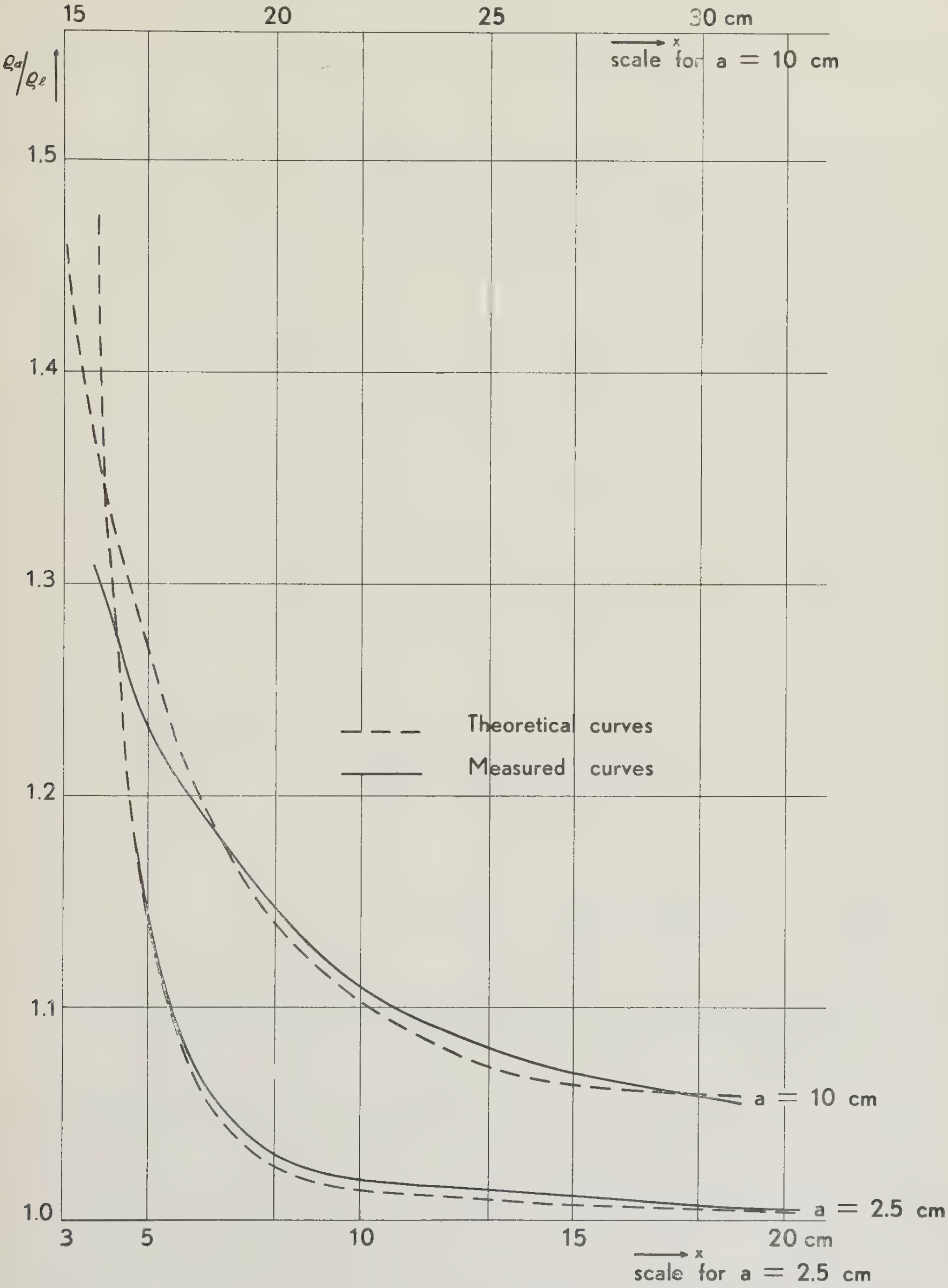

Fig. 5. Theoretical and measured curves of the ratio of apparent resistivity to resistivity of model material as a function of the distance from perspex tank wall.

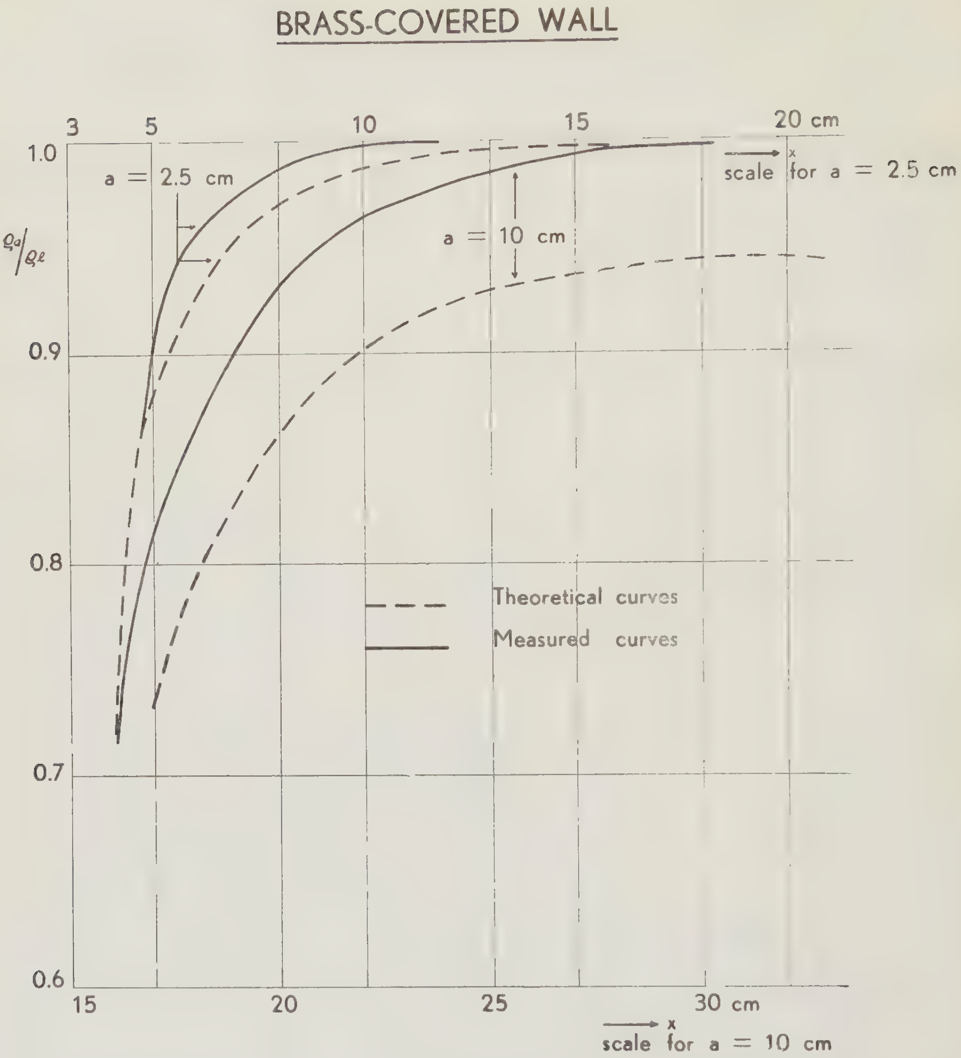

Fig. 6. Theoretical and measured curves of the ratio of apparent resistivity to resistivity of model material as a function of the distance from copper plate tank wall.

to behave more as a conductor when a solution with a higher resistivity is used. Comparing the extreme left ends of the relevant curves (Fig. 7a) seems to confirm this theoretical expectation. In the one case where this is not so, that of a $\frac{1}{20}$ N solution, where the tank wall behaves as a better conductor when a solution of lower resistivity is used, it can be seen that the current electrode was opposite one of the grid wires.

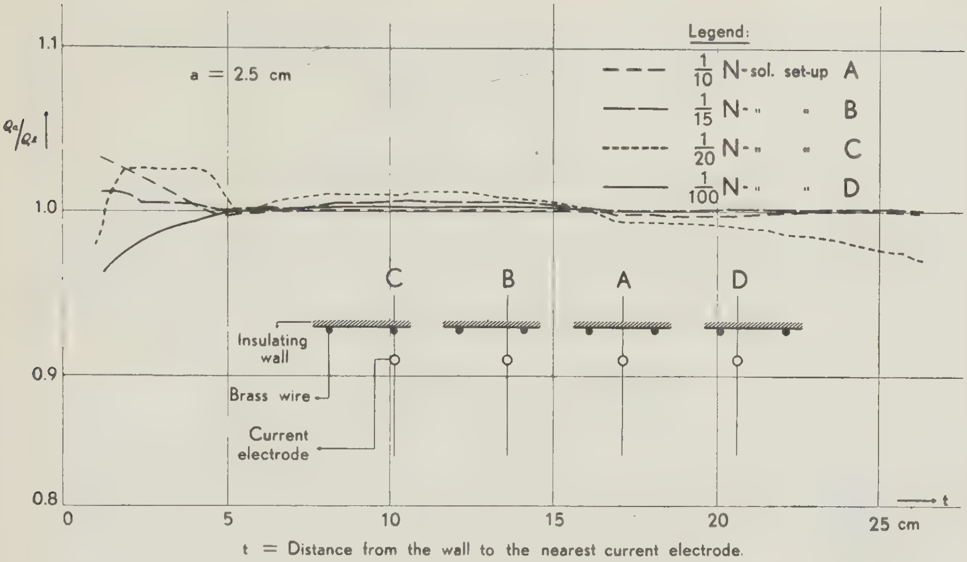

Fig. 7a

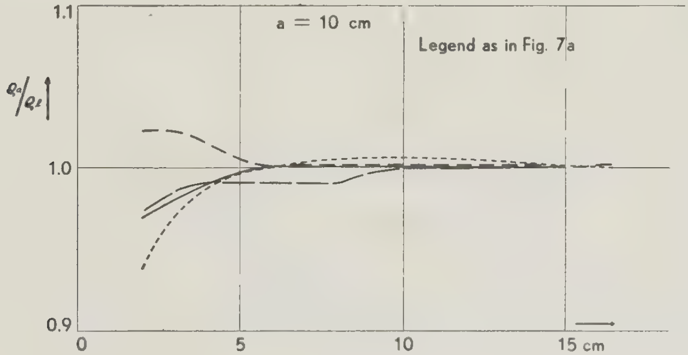

Fig. 7b

Fig. 7. Measured curves of the ratio of appearent resistivity to resistivity of model material as a function of the distance from perspex tank wall with brass grid.

From Fig. 7a it can be seen that the current electrode can be brought to within 5 cms of the tank wall before deviations due to the tank wall effect are observed. The effect can be seen for both values of *a*, and for a range of at least 0.1 to 0.6 ohm metre in the resistivity of the solution.

It can also be seen that when the distance from the tank wall to the nearest current electrode is less than 5 cms the wall material no longer behaves homogeneously, and the position of the electrode relative to the grid wires becomes important.

It was noticed that during the experiments the brass wire opposite the current electrode became blackened at the liquid surface. This corrosion, which is due to electrolysis, confirms that electro-chemical reactions between the solution and the tank wall do, in fact, take place.

Test on a Two Layer Case

A further test of the effectiveness of the grid covered tank wall was made by measuring a resistivity profile in a two layer case. The two layer model was made by suspending an insulating plate horizontally in the tank. The results obtained are shown in Fig. 8. The value of *a*/*h* (i.e. the electrode separation

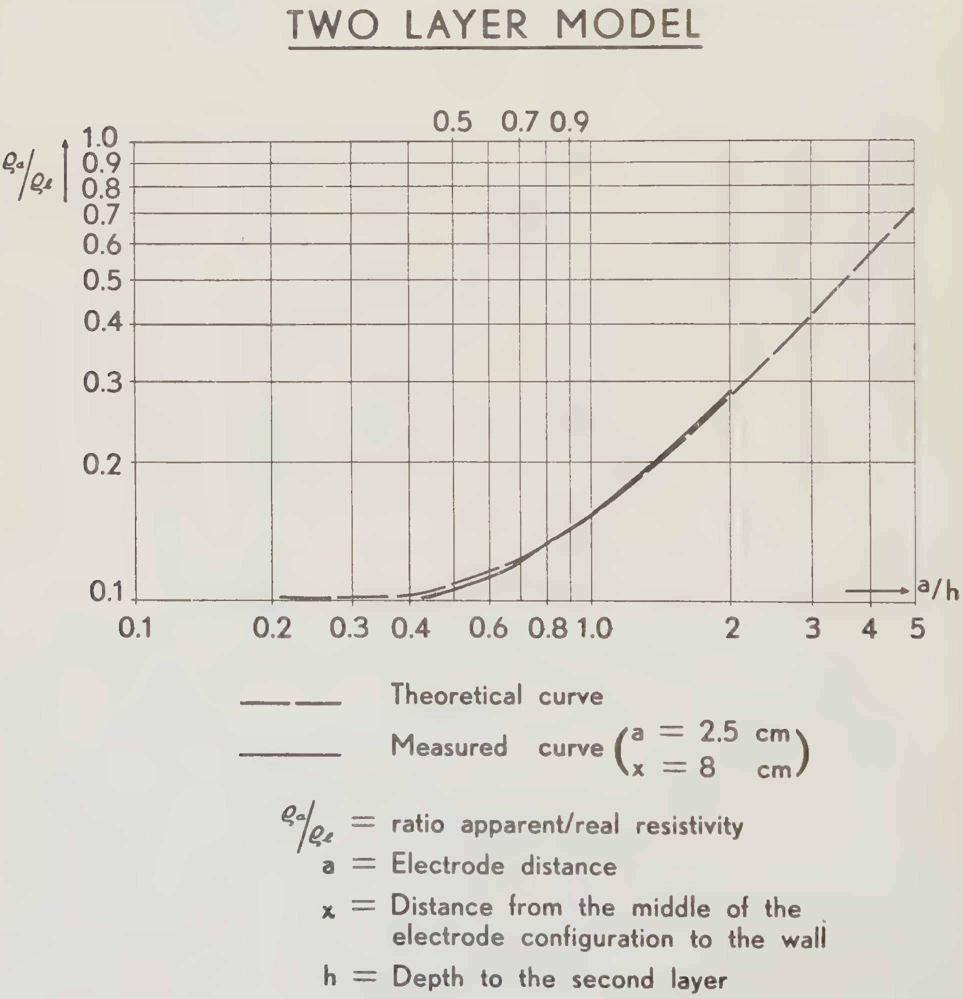

Fig. 8. Two layer case.

over the depth of the insulating plate) was measured by varying h from 1.5 to 60 cms, a being kept constant at 2.5 cms. The distance between the centre of the electrode configuration and the tank wall was kept constant at 8 cms. As in earlier experiments ρ_l was taken as being equal to the apparent resistivity measured in the middle of the tank with an electrode spacing of 2.5 cms and with the insulating plate on the bottom of the tank. Fig. 8 shows the observed curve together with the well known theoretical curve for the two layer case. It can be seen that the agreement between the curves is very satisfactory in spite of the very short distance between the nearest current electrode and the tank wall.

Conclusion

The experiments appear to verify the calculated tank wall effect in the case of an insulating tank wall. Covering the wall with a grid of brass wires enlarges the usable surface area of the model tank. It was found that the resistivity of the solution used has little influence on the usable surface area.

Acknowledgement

The author wishes to express his thanks to Prof. O. Koefoed, under whose direction these experiments have been performed, for his valuable advice and criticism.

SUPERMULTIPLICATION DES CHARGES ET DES SISMOGRAPHES AU SAHARA (ZONE NORD)*

PAR

GILBERT POMMIER **) ET HENRI RICHARD ***)

ABSTRACT

In desert countries, reflection seismic prospecting is often very difficult due to bad surface conditions, which adversely affect the quality of the reflections. From the beginning the Northern Sahara proved to be particularly unfavourable. In 1954 a series of systematic tests led to a shooting method which gave satisfactory results. This method used a high multiplicity of the shotholes (up to 100 per shotpoint) combined with a high multiplicity of geophones (up to, and sometimes more than 100 per trace). The method has proved effective and relatively economical to run since 1954. The evident conclusion is, that, under special conditions, high multiplicity may be very helpful in the future.

RÉSUMÉ

En pays désertique, la prospection sismique réflexion se heurte assez souvent à de grandes difficultés par suite des conditions de surface très défavorables à la bonne qualité des réflexions. Dès le début des recherches, la partie Nord du Sahara s'est révélée particulièrement hostile. Cependant des essais systématiques ont permis en 1954 de mettre au point une méthode satisfaisante, faisant appel à une supermultiplication des charges et des sismographes, allant jusqu'à une centaine de tirs multiples combinés parfois avec plus de cent sismographes par trace. Malgré des coefficients aussi élevés et les problèmes posés par le forage, la formule s'est montrée efficace et relativement économique depuis 1954, grâce à des dispositifs appropriés. La conclusion qui s'impose est que, sous certaines conditions, la supermultiplication peut rendre à l'avenir de très grands services.

INTRODUCTION

Pour des raisons matérielles et techniques, la prospection sismique réflexion se heurte en pays sec désertique à de grandes difficultés d'adaptation. Le niveau hydrostatique se place à des profondeurs excessivement grandes et le forage jusqu'aux terrains considérés comme favorables se relève malaisé et très coûteux malgré l'emploi de l'air comprimé. Les corrections de WZ sont imprécises par suite de la fréquente hétérogénéité des couches superficielles et surtout les réflexions enregistrées par les procédés classiques sont de qualité médiocre ou nulle. La partie Nord du Sahara ne fait pas exception à la règle et dès le début des prospections, il a fallu résoudre un certain nombre de problèmes.

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*) Presented at the Tenth Meeting of the European Association of Exploration Geophysicists, held in Hamburg, 16-18 May 1956.

**) Compagnie Française des Pétroles en Algérie.

***) Compagnie Générale de Géophysique.

Conditions de Surface et Premiers Essais

Les terrains de surface se présentent sous plusieurs aspects : masses calcaires très dures et abrasives, croûtes plus ou moins résistantes, dunes. Sous les calcaires ou sous la croûte on rencontre fréquemment des séries sableuses épaisses qui reposent sur des terrains compacts et transmettent mal l'énergie réfléchie tout en amplifiant le bruit. Sauf dans des secteurs privilégiés peu étendus, le rapport $\frac{\text{énergie réfléchie}}{\text{bruit}}$ est très faible, que l'explosion ait lieu à petite ou moyenne profondeur.

Les premières expériences poursuivies en tirant à 100 mètres et plus n'ont pas été fructueuses. Leur nombre en a été limité par la médiocrité des résultats, par leur prix très élevés et l'impossibilité matérielle de persévérer dans cette voie.

Après ces vaines tentatives, il a été reconnu en 1954 que le succès ne se trouverait finalement pas dans l'exploitation de tirs profonds, et qu'il ne restait plus qu'à chercher un remède dans l'utilisation systématique et à forte dose de la multiplication des sismographes et des charges celles-ci étant enterrées à faible profondeur : 1 ou 2 mètres, parfois davantage.

Les problèmes à résoudre portaient par conséquent sur :

— l'étude du bruit et le dispositif optimum

— le nombre de sismographes par trace et leur répartition

— le nombre de trous multiples et leur répartition

— les corrections de surface et de WZ

— le prix de revient.

Etude du Bruit

Il est nécessaire de rappeler que l'amélioration du rapport $\frac{\text{signal}}{\text{bruit}}$ par le procédé de la multiplication a fait l'objet de nombreuses études théoriques et expérimentales. En fait, un grand désaccord règne entre les sismiciens parce que trop souvent, les uns et les autres ne se placent pas dans des conditions identiques où simplement comparables. Les lois de propagation et d'entretien du bruit commencent à être connues, mais quelles que soient ces lois, on doit d'abord insister sur quelques faits d'observation.

On enregistre, semble-t-il, deux sortes d'ondes parasites.

a) *Les parasites "organisés"* — Ces parasites se caractérisent par les traits suivants:

— Leur vitesse apparente de propagation est assez bien définie et à peu près constante sur une distance de quelques dizaines ou centaines de mètres et plus. Sur cette distance, leur forme est à peu près invariable et leur amortissement progressif. Suivant les trains d'onde, la vitesse est comprise entre 200 mètres/seconde et 2000, pouvant atteindre 5000 dans les terrains calcaires.

— En pratique, ces parasites sont constitués par des ondes directes ou réfractées sur des marqueurs continus.

— Ils sont approximativement orientés dans la direction du tir.

— Ils suivent de près les premières ondes réfractées (fig. 1); et dans certains

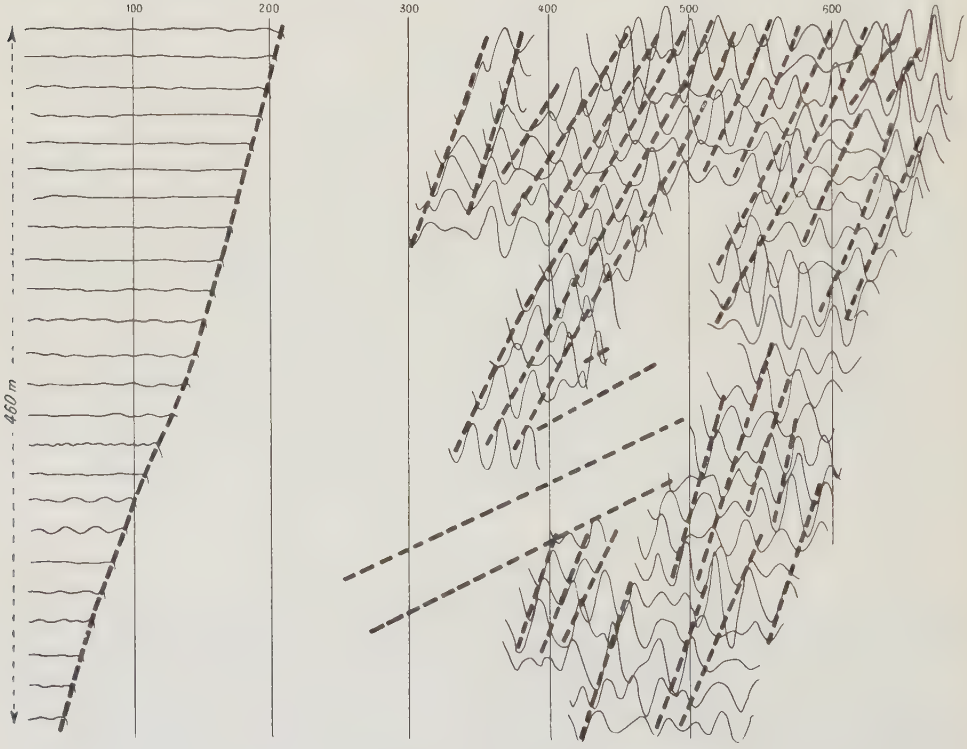


Fig. 1. Exemple de parasites "organisés".

Example of non-random noise.

cas se répètent pendant un temps assez long à la manière de réfractions multiples: répliques de dromochroniques (fig. 2).

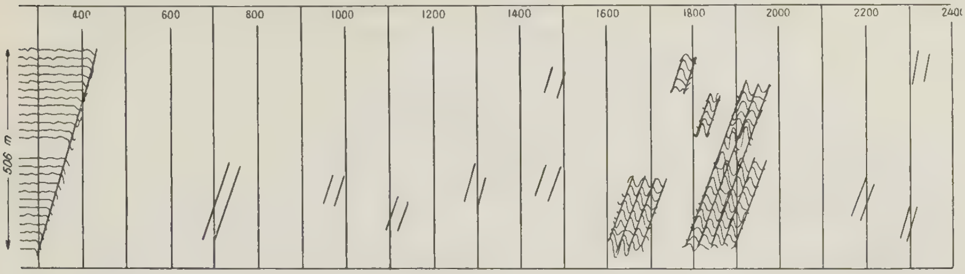


Fig. 2. Exemple de parasites "organisés". Réfractions multiples caractérisées.
Example of non-random noise; multiple refractions.

— Quand leur vitesse apparente est petite (fig. 3) leur temps de passage est souvent en relation étroite avec la position des sismographes: plus les sismographes sont éloignés, plus les parasites arrivent longtemps après l'explosion, avec une tendance à s'amortir assez rapidement.

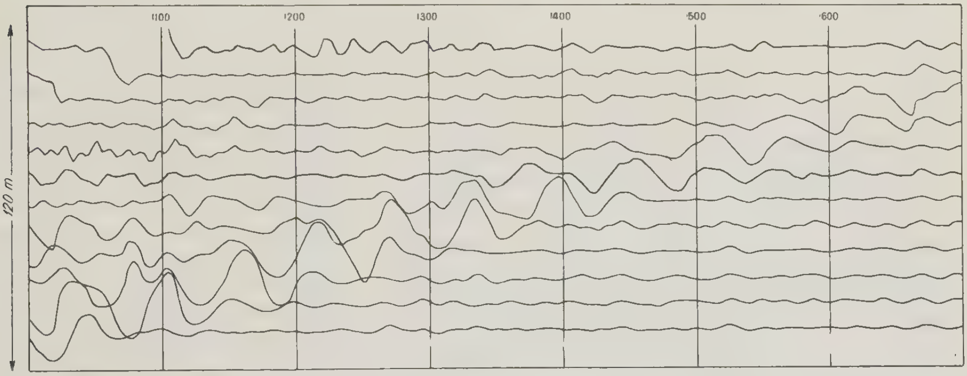
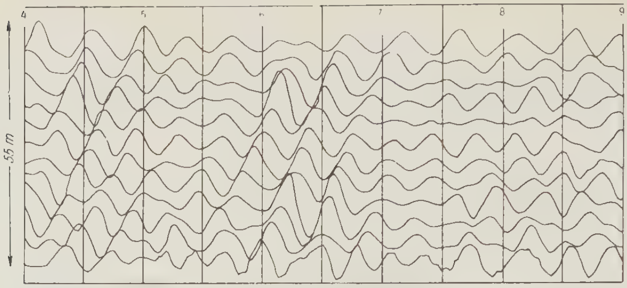


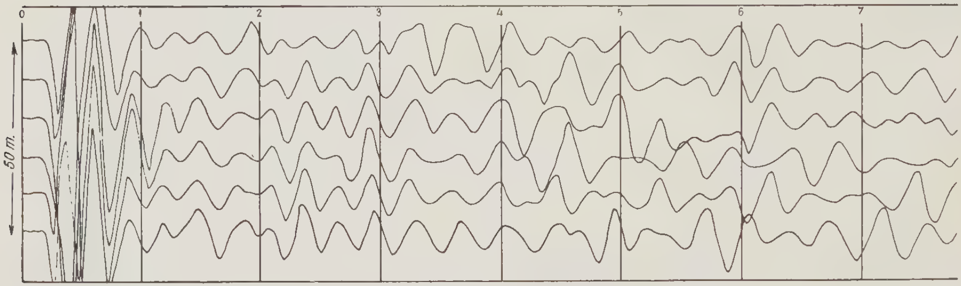
Fig. 3. Exemple de parasites "organisés". Vitesse de propagation très lente.
Example of non-random noise; very low velocity of propagation.

b) *Les parasites "désorganisés"* — Ceux-ci s'enregistrent un certain temps après l'explosion, soit qu'ils succèdent aux bruits "organisés" soit qu'ils interfèrent avec eux (fig. 4 et fig. 5).

— Leur vitesse apparente varie rapidement sur de petites distances: quelques mètres .... Il en est de même de leur amplitude. Par exemple, ils ap-



Ligne longitudinale de sismographes
Longitudinal seismometer line



Ligne tranversale de sismographes
Transverse seismometer line

Fig. 4. Passage de parasites "organisés" à parasites "désorganisés"
Interference between non-random and random noise.

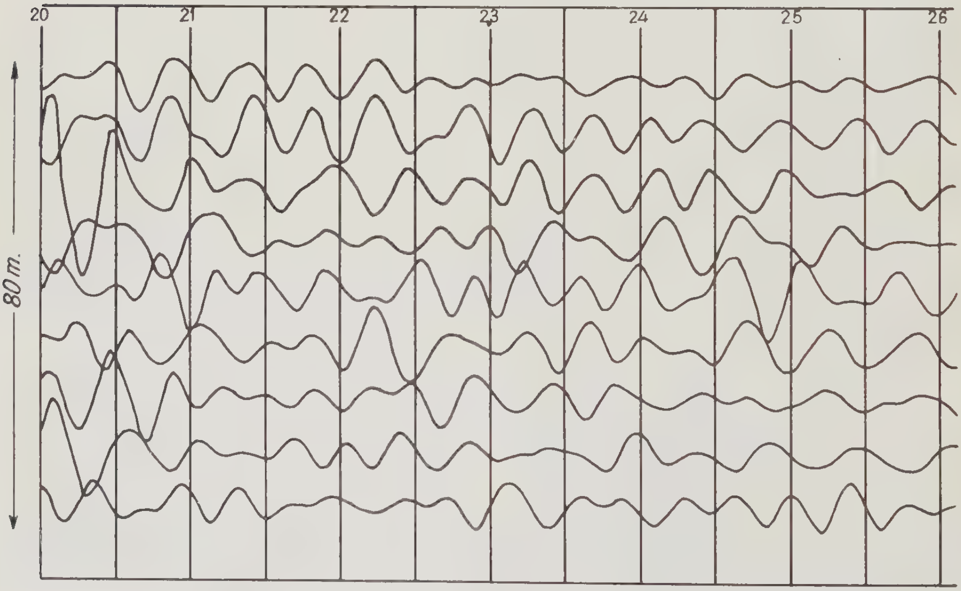


Fig. 5. Exemple de parasites "désorganisés".
Example of random noise.

paraissent et disparaissent sur une longueur d'une dizaine ou d'une vingtaine de mètres.

— Leur orientation est quelconque.

— Leur importance relative dans le niveau total du bruit augmente souvent avec le temps.

Bien que cette distinction entre parasites organisés et désorganisés paraisse schématique, il n'est pas surprenant que les calculs théoriques et les expériences conduisent à des conclusions divergentes selon *la proportion des différents parasites dans le niveau du bruit et leurs caractéristiques respectives.*

En fonction de: la constitution du sol, la profondeur de tir, la distance explosion-sismographe, le temps écoulé depuis l'explosion etc.... on peut s'attendre à rencontrer un grand nombre de cas plus ou moins complexes. En pratique, si les parasites "organisés" sont prépondérants, il y a intérêt à adopter une multiplication longitudinale et au besoin à pondérer les sismographes ou les charges. Si les parasites "désorganisés" l'emportent une disposition en étoile ou en réseau est préférable. Mails il arrive qu'un schéma valable dans la première seconde après l'explosion, soit médiocre pendant la deuxième seconde et inversement. Il peut se faire que la meilleure formule pour un tir à 20 mètres de profondeur, ne soit plus la meilleure pour un tir à 2 mètres, etc. etc.

APPLICATION AU SAHARA - DISPOSITIF OPTIMUM -

Les conditions sahariennes ne sont pas uniformes. Sur certains profils le bruit ,,organisé" du type (Fig. 1) et (2) est particulièrement gênant, pendant un temps plus ou moins long. Il paraît en relation étroite avec des réfractions multiples sur marqueur peu profond. Ailleurs et principalement dans les parties défavorables du Nord, les parasites sont très désordonnés. En outre, les réflexions les plus difficiles à enregistrer arrivent tard, 1 seconde et plus après l'instant de l'explosion. L'expérience a rapidement montré que la multiplication sur plusieurs lignes longitudinales parallèles (Fig. 6) était la plus pratique, celle qui, sans être toujours la meilleurs, présentait des avantages essentiels.

1°) Sur une superficie donnée, le procédé permet de réaliser un très fort coefficient de multiplication. Cette superficie, couverture d'une trace ou de l'ensemble des explosions, est limitée pour plusieurs raisons bien connues. Anomalies altimétriques ou de WZ, courbure d'indicatrice (ΔT) et pendages faussent le jeu de la multiplication quand les déphasages entre signaux ajoutés sont trop grands. Compte-tenu des pendages sahariens excessivement faibles, il est souvent possible de couvrir des rectangles mesurant 100 à 200 mètres de côté.

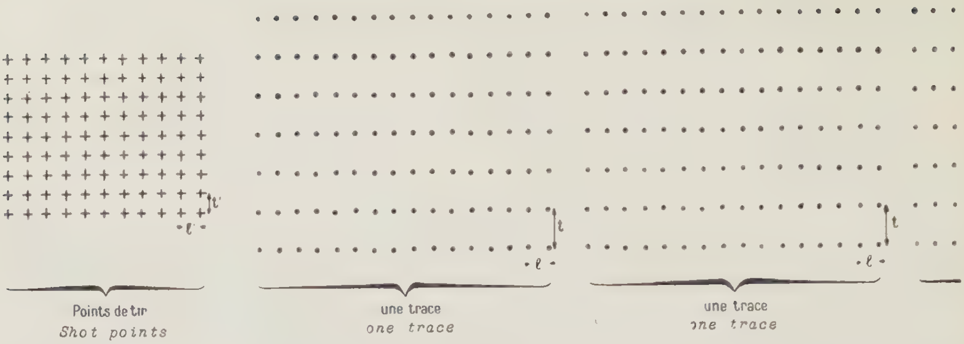


Fig. 6. Dispositif type.
Type pattern.

2°) La mise en place est rapide et peu coûteuse, sous réserve que les lignes de sismographes soient jointives entre elles d'une trace à l'autre (Fig. 6).

3°) On combine les avantages de la multiplication longitudinale (atténuation des parasites "organisés") et du réseau (atténuation des parasites "désorganisés").

4°) La recherche expérimentale des écartements optima entre explosions ou entre sismographes sur les lignes longitudinales, et entre lignes est facile. Le nombre de paramètres est en effet petit (Fig. 6):

— *l* distance longitudinale entre sismographes
— *t* distance transversale entre lignes de sismographes
— *l'* distance longitudinale entre explosions
— *t'* distance transversale entre lignes d'explosions.

L'influence des 4 paramètres a été examinée sur les parties de films enregistrées 1 à 2,5 secondes après l'explosion. C'est là que se trouvent des réflexions profondes intéressantes et que le rapport $\frac{\text{signal}}{\text{bruit}}$ est le plus petit. Les études ont été conduites dans les conditions de tir normales: trous peu profonds, charges comprises entre 0,3 et 1 kilog.

NOMBRE ET REPARTITION DES SISMOGRAPHES PAR TRACE

Les essais ont été d'abord limités à la comparaison systématique des résultats donnés par une ligne longitudinale de 12 ou 18 sismographes, *l* étant égal à 5 puis à 10 mètres. Il a été rapidement constaté que pour $l = 10$, le niveau du bruit était 1,3 à 1,4 fois plus petit que pour $l = 5$. Ce premier résultat a fait adopter des lignes de 12 ou 18 sismographes couvrant par conséquent une longueur de 110 ou 170 mètres.

La comparaison a porté ensuite sur le bruit enregistré par plusieurs lignes longitudinales accouplées, l étant égal à 10 mètres, tandis que t prenait les valeurs 5-10-20 mètres. On a observé que le passage de 5 à 10 mètres marquait une grande amélioration et que le progrès réalisé de 10 à 20 mètres quoique petit n'était pas négligeable, à quelques exceptions près.

La conclusion a été qu'il y avait tout avantage à adopter l au moins égal à 10 mètres, t au moins égal à 20 mètres, le niveau du bruit étant dans ce cas très approximativement divisé par $0{,}8\sqrt{n}$ (n = nombre assez grand de sismos branchés sur la trace).

Les dispositifs sismographiques ont alors été choisis afin d'avoir n le plus grand possible.

Par trace: 6 lignes de 18 sismographes soit 108 sismographes répartis dans un rectangle de 170 mètres de long sur 100 de large, représentant, 1,7 hectare, ou bien 7 lignes de 12 sismographes soit 84 sismographes (110 mètres × 120 mètres = 1,32 hectare).

Le nombre de traces a été fixé à 6; 3 entre les points de tirs, la distance entre points de tir étant de 400 à 600 mètres. L'exploitation des régions difficiles a montré qu'il ne fallait pas descendre au-dessous d'une centaine de sismographes par trace, la surface couverte étant de 1 à 2 hectares. En outre, là où le bruit organisé était assez intense, il a été vérifié qu'il y avait intérêt à étaler les traces dans le sens longitudinal. = dans le sens du tir

En certains points, des films médiocres ont été interprétés en composant toutes les traces d'un enregistrement ce qui portrait à environ 500 le nombre de sismographes multiples.

Nombre de Trous Multiples, Repartition

Le problème des trous multiples est plus important que celui des sismographes multiples. Il est en effet plus facile et beaucoup moins coûteux d'utiliser quelques dizaines ou centaines de sismographes qu'un nombre de charges enterrées équivalent, même si les charges sont à faible profondeur.

Etant donné l'incidence plus grande sur les prix de revient on ne doit pas hésiter à tenter de nombreuses expériences pour mesurer l'atténuation du bruit en fonction de l'écartement des charges, et chiffrer avec précision l'écartement le plus économique. Il paraît donc nécessaire d'insister sur les expériences et leurs résultats.

Problème posé: La profondeur de tir et la charge élémentaire étant données, on se propose de mesurer le niveau du bruit et son atténuation, en fonction de la distance entre charges.

Sans insister sur les détails nous signalons que:

— les charges expérimentales sont enterrées à la profondeur habituelle: 1 à 2 mètres, parfois davantage. Les explosions ont lieu dans des trous vierges.

Les trous sont assez écartés pour empêcher que l'effet d'un tir soit altéré par celui des tirs environnants.

— Les charges expérimentales sont du même poids que les charges habituelles, 0,3 à 1 Kilog.

— Les sismographes sont assez éloignés des explosions: 200 à 300 mètres, ce qui correspond aux conditions moyennes de travail.

— Le bruit n'est mesuré avec précision que si le rapport $\frac{\text{signal}}{\text{bruit}}$ est très petit (inférieur à 3%).

Au cours des expériences, on a mesuré le bruit provoqué sur un sismographe par le tir simultané de 8 charges disposées, soit un sur une ligne longitudinale, soit sur une ligne transversale, les valeurs de l' ou t' étant de 0-4-8-16 mètres, la longueur de ligne de tir variant ainsi de 0 à 28-56-112 mètres.

Champ de tir (Fig. 7): Le champ de tir est aussi symétrique que possible. Par exemple:

— une ligne médiane a de 32 trous écartés de 4 m. Ces 32 trous sont tirés isolément ou en 4 rafales de 8 trous successifs.

— deux lignes *b, b'* symétriques par rapport à a. Chaque ligne a 8 trous distants de 16 m.

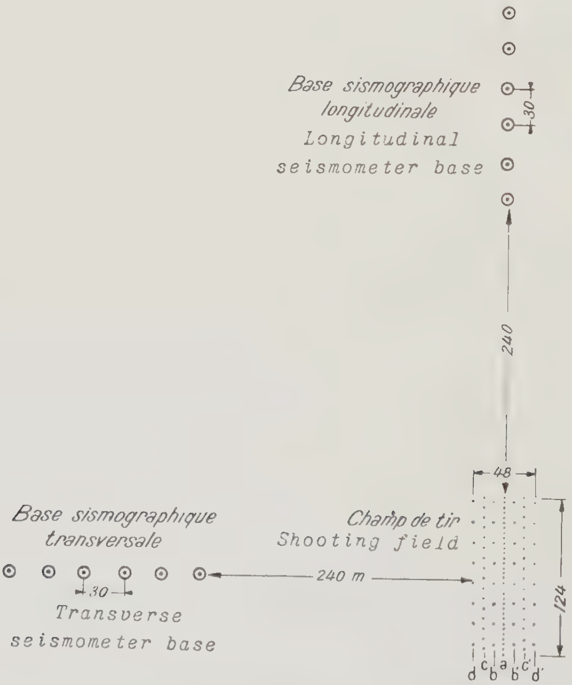

Base sismographique longitudinale
Longitudinal seismometer base
30
240
48
Champ de tir
Shooting field
124
240 m
Base sismographique transversale
30
Transverse seismometer base
d c b a b c' d'

Fig. 7. Etude du bruit: plan de position.

Noise study: location map.

— deux lignes *c*, *c'*. Chaque ligne a 16 trous distants de 8 m.

— deux lignes *d*, *d'* identiques à *b*, *b'*.

L'ensemble permet de réaliser:

sur *a*: 32 tirs à charge unique ou bien 4 tirs multiples, écartement de 4 mètres.

sur *c*, *c'*: 4 tirs multiples écartement 8 mètres.

sur *b*, *b'*, *d*, *d'*: 4 tirs multiples écartement 16 mètres.

Grâce à cette distribution on répartit les anomalies du terrain et on conserve pour les divers écartements essayés, une distance moyenne constante entre l'ensemble des tirs et les bases de mesure.

Bases de mesure. — Deux bases sismographiques placées à 240 m du champ de tir comprennent chacune 6 traces écartées de 30 m (1 sismographe par trace). La longitudinale se place dans l'axe des lignes de tir, la transversale lui est perpendiculaire.

Mesure du bruit. — Le niveau du bruit est mesuré sur chaque trace dans deux tranches de temps hors de la plage des réflexions. Notons d'ailleurs qu'ici, avec un seul sismographe et un tir multiple de 8 charges, l'énergie réfléchie est négligeable sur tout le film. Pour faire apparaître les réflexions, il faudrait 100 sismographes et 100 explosions soit, un coefficient total de multiplication de 10.000. On dispose pour chaque tir de 2 valeurs du niveau du bruit par trace soit 12 valeurs par base et 24 au total. Pour réduire la dispersion des mesures, on s'est contenté de mesurer la moyenne enregistrée par chaque base (moyenne de 12 valeurs).

L'étude statistique a montré ensuite que les moyennes sur chaque base, longitudinale et transversale, étaient sensiblement égales. Il a donc paru légitime de ne retenir pour chaque enregistrement que la moyenne des 24 mesures.

Tir unique. — La mesure du bruit provoqué par des tirs uniques a pour but de comparer les effets de plusieurs explosions se répétant dans des conditions de terrain en apparence identiques. En outre, elle fait connaître au coefficient 8 près le niveau du bruit qui serait enregistré par 8 explosions multiples dont l'écartement serait égal à 0.

Pour chaque tir on mesure d'une part le *niveau du bruit* sur les deux bases sismographiques, d'autre part *le niveau de l'énergie* enregistré sur la base transversale. L'énergie est chiffrée par l'impétus de la première onde réfractée arrivant sur les sismographes. Il a été vérifié que la déviation de l'impétus de la première onde réfractée arrivant à des sismographes assez éloignés varie de la même façon sur tous les sismographes et constitue un critère du "rendement sismique", critère que, à un coefficient près, on convient d'appeler un peu sommairement "l'énergie" dégagée par l'explosion. On a donc le moyen de mesurer en plusieurs points la valeur relative de "l'énergie" dégagée par une explosion et de la comparer au niveau du bruit. (Il n'est pas tenu compte de la base longitudinale car sa distance aux différentes explosions varie entre des limites assez larges).

Le bruit enregistré pendant un certain temps après l'explosion est égal à l'aire couverte par la trace de part et d'autre de sa position moyenne.

Sur la figure 8, sont condensés les résultats donnés par les 32 explosions échelonnées sur la ligne a de la figure 7. Les tirs sont classés par énergie décroissante. On porte en ordonnées les valeurs relatives du bruit, de l'énergie et du rapport bruit/énergie. On observe une forte dispersion, mais d'une explosion à l'autre, le bruit varie comme l'énergie. Il ne s'agit là que d'une approximation car, en gros, le rapport bruit/énergie croît de 0,8 à 1,3 quand le rendement de l'explosion diminue.

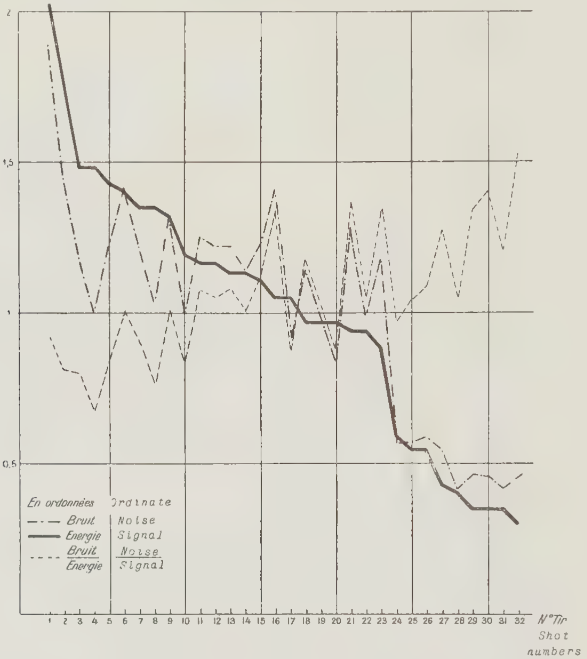


Fig. 8. Tirs uniques. Classés par énergie décroissante.

Ecart moyen arithmétique { Bruit: 0,30
Energie: 0,35 }

Single shots. Arranged in order of decreasing signal strength.

Average deviation { noise: 0.30
signal: 0.35 }

Sur la figure 9, on analyse pour les 32 tirs la dispersion du bruit et de l'énergie. On porte en ordonnées les valeurs mesurées pour chaque explosion et on déduit la courbe des dispersions qui donne lieu aux remarques suivantes:

1°) La dispersion de l'énergie est en apparence plus grande que celle du bruit. Ceci s'impute à une raison métrologique. L'énergie n'est mesurée que sur 6 déviations, tandis que le bruit est défini par plusieurs dizaines d'élongations.

2°) Deux familles d'explosions se dessinent. 9 sur 32, soit 25 à 30% ont une efficacité anormalement faible, égale en moyenne à 40% de celle des 23 autres.

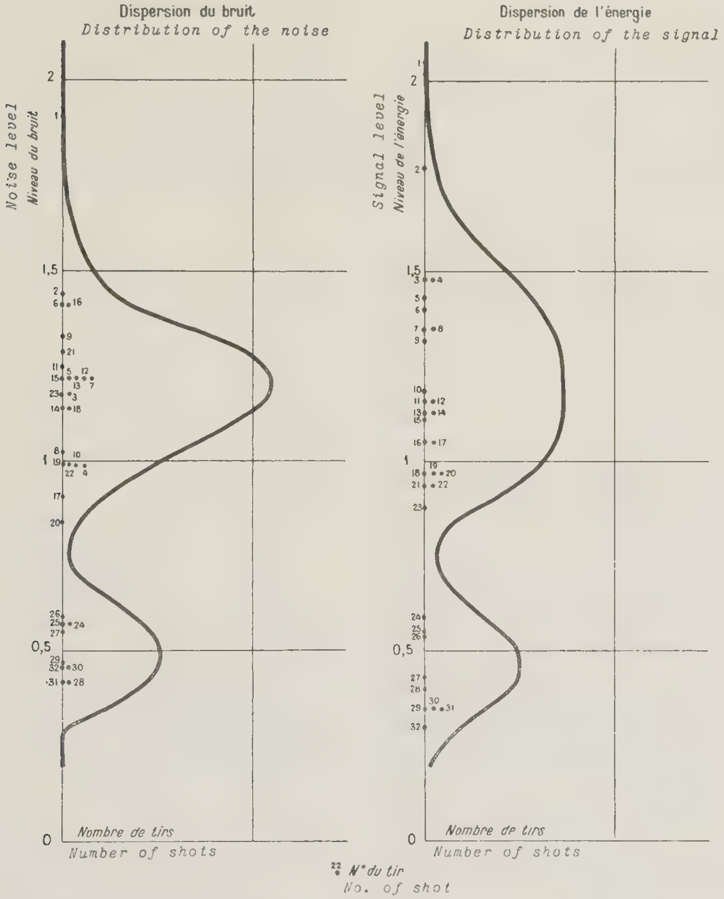


Fig. 9. Tirs uniques.

Single shots.

Dans ces conditions on se demande s'il n'existe pas en cet endroit deux catégories d'explosions, dont l'une contiendrait les explosions défectueuses: bourrage défectueux par exemple.

Les expériences faites dans un autre secteur ont montré une dispersion plus petite (écart moyen arithmétique 0,2 au lieu de 0,3) avec une moindre tendance à distinguer deux familles de tirs.

Tirs multiples. — Les mesures du bruit dans le cas de 8 charges multiples conformément au plan de la figure 7 ont en lieu en trois stations totalisant près de 300 forages. Les statistiques déduites de la masse de mesures figurent sur la figure 10.

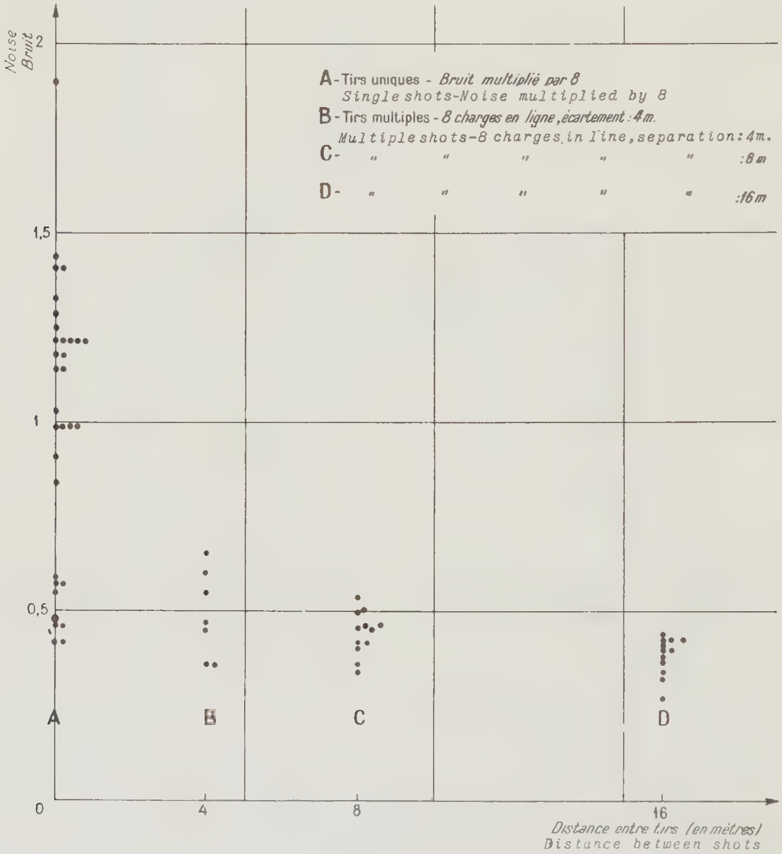


Fig. 10. Tirs multiples (8). Niveau du bruit en fonction de la distance entre charges.
Multiple shots (8). Noise level as a function of the distance between charges.

A groupe les valeurs du bruit des 32 tirs simples. Les chiffres ont été multipliés par 8 de manière à chiffrer le bruit qui serait produit par 8 charges multiples, écartement = 0.

B groupe 8 valeurs pour un écartement de 4 mètres.

C groupe 12 valeurs pour un écartement de 8 mètres.

D groupe 12 valeurs pour un écartement de 16 mètres.

La dispersion en A n'est pas excessive si l'on tient compte du nombre élevé de déterminations. Pour B, C, D, la dispersion se révèle beaucoup plus faible puisque chaque opération fait la moyenne des effets de 8 explosions.

A partir de toutes ces valeurs, on calcule que les valeurs relatives probables du niveau du bruit seraient de:

1,07 à 0,93 écartement = 0
0,53 à 0,44 écartement = 4 m
0,46 à 0,42 écartement = 8 m
0,40 à 0,37 écartement = 16 m

La courbe du bruit en fonction de l'écartement entre charges se placerait dans la zône couverte de hachures sur la figure 11.

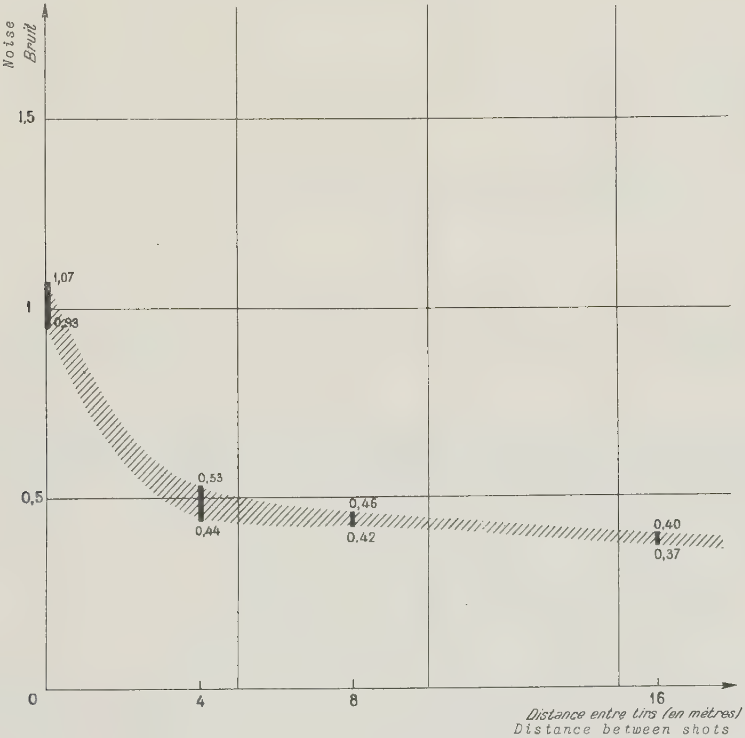


Fig. 11. Tirs multiples (8). Variation du niveau du bruit, en fonction de la distance entre charges.

Multiple shots (8). Variation of the noise level as a function of the distance between charges.

Le tir multiple de 8 charges longitudinales ou transversales permet de diviser par près de 2,6 le niveau relatif du bruit si les charges sont assez écartées. Il y a avantage à adopter des écarts de l'ordre de 10 m et davantage. L'efficacité de la multiplication serait plus grande si toutes les charges avaient le même "poids" dans la combinaison statistique de leurs effets. On constate en effet que l'efficacité de 8 charges multiples assez étalées est de 2,6 environ, valeur intermédiaire entre $\sqrt{8}$ et $\sqrt{6}$. Comme on a vu que 25 à 30% des charges pouvaient avoir un rendement à peu près égal à 40% du rendement "normal", cette dispersion suffit à expliquer que l'efficacité soit un peu inférieure à $\sqrt{8}$.

La conclusion de ces essais réalisés, rappelons le, avec près de 300 trous expérimentaux a été qu'il fallait prendre l' et t' compris entre 10 et 20 mètres, le niveau du bruit étant alors divisé par $K\sqrt{p}$, $p =$ nombre assez grand de tirs multiples, K valeur un peu inférieure à l'unité.

Les dispositifs adoptés ont été les suivants:

— 7 lignes de 10 trous (10 mètres entre trous sur la ligne, 20 mètres entre lignes) soit plus d'un hectare.

— 10 lignes de 10 trous répartis uniformément dans un carré de 90 × 90 mètres, soit 0.81 hectare etc....

Coefficient global de multiplication: Finalement on a recours dans les secteurs difficiles à un coefficient global de multiplication: n sismos multiples combinés avec p explosions, très élevé, de l'ordre de 100 × 100 = 10.000 et de 60.000 si 6 traces sont composées ensemble. Le rapport $\frac{\text{signal}}{\text{bruit}}$ est alors très approximativement 80 à 200 fois plus grand que dans le cas de 1 sismo et 1 tir uniques. Sur la Fig. 12 on représente un exemple d'enregistrement obtenu dans ces conditions. Quand les travaux se déplacent vers le sud la situation s'améliore, et les coefficients sont moins forts: 30 à 40 sismos par trace combinés avec 10 à 30 tirs.

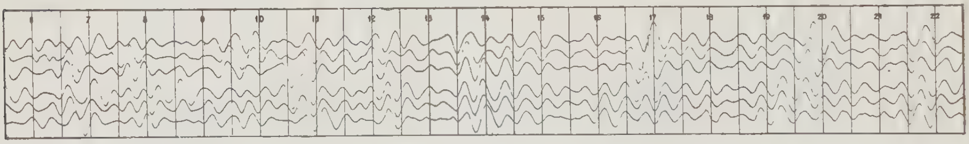


Fig. 12. Un exemple de film. 100 tirs multiples, 108 sismos/trace.
Sample seismogram. 100 charges per shot, 108 seismometers per trace.

Critique technique de la méthode: La supermultiplication à base de tirs à faible profondeur trouve au Sahara un très vaste champ d'application, et permet d'obtenir des coupes de qualité dont on donne un exemple sur la figure 13. Dans ce pays désertique il est commode d'étaler les dispositifs sur le terrain. En outre les pendages sont très faibles, la distance entre traces peut souvent dépasser 100 mètres, etc.... Mais la méthode encourt deux critiques, l'une

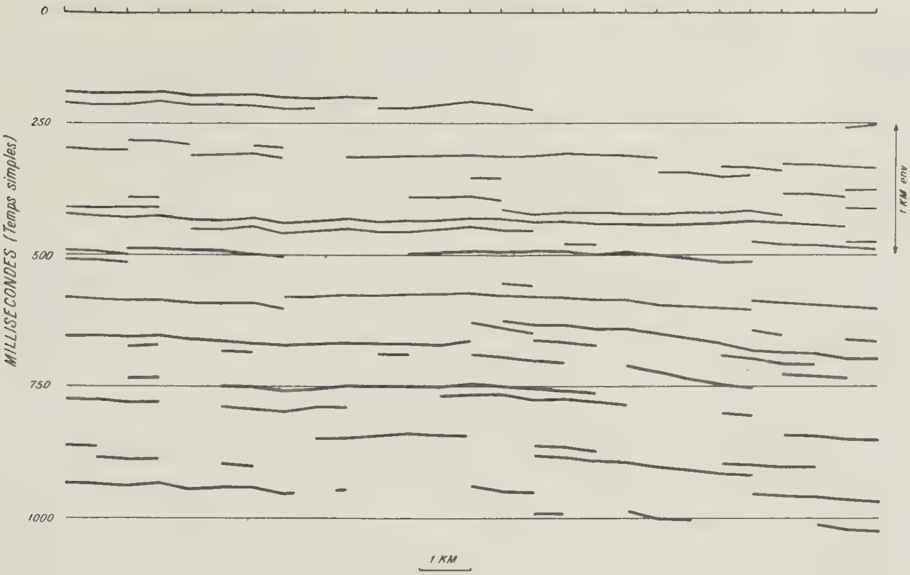


Fig. 13. Un exemple de coupe. 100 tirs multiples, 108 sismos/trace.

Sample section. 100 charges per shot, 108 seismometers per trace.

s'adressant aux corrections de surface et de *WZ*, l'autre aux défauts classiques de la multiplication.

Corrections de surface et de WZ: L'absence de forages assez profonds avec mesures des temps verticaux tout le long des profils, interdit les corrections précises. Cet obstacle se tourne facilement.

1°) On s'attache à suivre les horizons continus peu profonds. Ces horizons en général subhorizontaux servent de niveaux de référence.

2°) Les mesures indirectes de vitesse par la méthode classique de ΔT entre la surface et les repères peu profonds, sont assez précises en première approximation pour suivre les variations de vitesse dans la couverture.

3°) Le contrôle des corrections par quelques forages judicieusement placés n'a lieu qu'en fonction de l'ensemble des résultats d'une campagne.

Défauts classiques de la multiplication. — La multiplication sur une grande étendue empêche l'étude des miroirs petits ou pentés, entraîne des erreurs, etc. De tels griefs ne sont pas valables au Sahara car les principales séries sont continues et la tectonique calme.

Par surcroît on fait en sorte que les traces ne se chevauchent pas. Les traces étant absolument indépendantes, les corrélations sont mieux garanties.

En revanche, les anomalies de *WZ* à l'intérieur de la couverture d'une trace sont parfois gênantes. Les possibilités qu'offre l'enregistrement magnétique y porteront remède.

Prix de revient. — La forage par points de tir de 30 à 100 trous peu profonds est relativement coûteux. Le prix en a été abaissé depuis 1954 par l'adaptation du chantier et l'emploi de marteaux. Voici par exemple les rendements mensuels dans une équipe opérant dans des conditions très dures (6 postes de marteaux).

Nombre de trous, dans un mois	: 17 000
Nombre de mètre forés	: 17 000
Kilomètres de profil	: 120

Avenir de la supermultiplication. — La méthode que nous avons décrite a fait ses preuves depuis un an et demi et nous sommes persuadés qu'elle est perfectible. La supermultiplication se pratique d'ailleurs avec d'autres procédés tels que chutes de poids, tirs en surface qui ont leurs avantages et inconvénients respectifs que nous ne discuterons pas ici.

Il convient cependant de signaler que les explosions dans des trous peu profonds offrent jusqu'à maintenant le gros avantage de ne pas imposer le travail en off-set.

Quelle que soit la formule, il est de plus en plus démontré que la multiplication à forte dose apporte d'excellents résultats dans des secteurs qui paraissaient condamnés. Mais ses possibilités actuelles en sont limitées par le fait que l'on ne combine que des sismographes groupés sur la même trace où des tirs simultanés. Désormais, grâce à l'enregistrement magnétique qui doit permettre après correction, la composition automatique entre des traces appartenant à un ou plusieurs enregistrements, les progrès continueront à se développer. Les applications futures (certaines ont déjà été lancées) auront une importance décisive dans la mesure où elles seront couronnées de succès. Nour citerons:

— Essai d'élimination des *réflexions multiples.* Dans ce cas, on tiendra compte par exemple de ce que, très souvent, les corrections ΔT ne sont pas les mêmes pour les réflexions réelles et multiples.

— Essai de discrimination entre des *réflexions discordantes* arrivant simultanément, par sélection des réflexions ayant un gradient déterminé.

— Diminution de la consommation d'explosifs, emploi de micro-charges, utilisation d'autres sources d'énergie, *par intégration* des effets de plusieurs chocs répétés.

— *Suppression éventuelle des forages sismiques,* en réflexion ou en réfraction, sur certains périmètres.

On peut enfin se demander si l'étude approfondie du *caractère des réflexions* ne sera pas facilitée par la supermultiplication. Il est en effet prouvé que dans bien des cas celle-ci est capable de filtrer tout ou partie du bruit en se substituant presque complètement aux filtres classiques. Il y aurait donc là un excellent moyen de dégager sans déformation aucune la forme des signaux réfléchies. Au moment où l'exploration des *pièges stratigraphiques* prend dans plusieurs bassins tellement d'importance, il s'agirait, au prix de certaines précautions, d'analyser les moindres détails d'un enregistrement, de les interprèter, de tenter des corrélations à distance. De même que le continuous velocity logging a donné naissance à la notion de film synthétique, de même l'opération réciproque: remonter du film réel au log de vitesses, donc à une sorte de coupe lithologique, pourrait être envisagée. Bref, la supermultiplication est appelée à rendre à l'avenir de très grands services soit dans les opérations courantes, soit dans les travaux expérimentaux.

THE VARIATION WITH DISTANCE OF THE AMPLITUDE OF CRITICALLY REFRACTED WAVES *)

BY

P. N. S. O'BRIEN **)

Abstract

Amplitude measurements have been made of the height of the first peak of an arrival refracted from a shallow refractor. If the amplitude is assumed to decay as the inverse mth power of the distance, the least squares value for m is found to be 2.16 ± .04. Because of this value and because of the character of the recorded event it is concluded that the arrival is a simple critical refraction. After applying the theoretical 'spread' factor for critical refraction there remains a residual attenuation of 1.96 ± 0.28 decibels per 1000 feet. The predominant frequency in the pulse is about 20 c.p.s. and this attenuation agrees with the losses found for such a frequency by extrapolation of the published results of other workers. Although no evidence could be seen on the records for a change of pulse frequency with distance, the quoted result would be consistent with a dependence of residual attenuation on the first power of the frequency, and would be inconsistent with a dependence on the second power of the frequency.

It is concluded that studies of the amplitudes of refracted events will give useful estimates of the attenuation factors of rocks.

Introduction

There has recently been renewed interest in the possibility of using quantitatively the amplitudes and waveforms of the various events which appear on a seismic record. Such measurements must be made if a thorough understanding of seismic wave propagation is to be obtained. But there may also be more immediate uses. For instance, by measuring the attenuation of seismic waves due to elastic imperfections of the media through which they travel, it might prove possible to identify the media; different rock types may have different attenuation coefficients.

The 'refraction' method of seismic prospecting appears well suited to the measurement of attenuation coefficients, for each refractor is sampled over the same distance as the length of the spread, and this is seldom less than a few thousand feet.

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*) Presented at the Twelfth Meeting of the European Association of Exploration Geophysicists, held in Brussels, 5-7 June 1957.

**) The British Petroleum Company Limited, London.

However, before any geologically useful results can be obtained from amplitude measurements it is necessary to correct for those variations which are due solely to the normal spreading out of the energy as the wavefront gets larger and larger. This correction factor is usually called the 'geometrical' or 'spread' factor.

For the refracted arrivals used in seismic prospecting, it is known from analysis (e.g. Cagniard 1939, Heelan 1953) of the simple case in which an extensive medium of one velocity overlies a second medium of greater velocity, that the amplitude of the refracted wave (or, head wave) should vary, to a certain approximation, as $d^{-1/2}L^{-3/2}$ where d is the orthogonal projection on the interface of the distance between the source and detector, and L is the distance the wave has travelled in the lower medium, see figure 1.

This factor is an approximate one, which is only closely true for points whose distance from the ray critically reflected at the interface is 'large' compared with a 'wavelength'. Neither 'large' nor 'wavelength' are easily definable, though for a given type of pulse it should be possible to calculate for what distance the factor is a good approximation. As a rough guide it may be taken to hold for distances greater than about twice the predominant wavelength in the pulse spectrum. This law of decrease of amplitude with distance has been verified experimentally in the laboratory, using an ultrasonic source whose predominant wavelengths were an inch or two (O'Brien 1955). This paper reports on some field experiments whose results confirm the law under normal exploration conditions, and gives the attenuation coefficient for a Triassic marl.

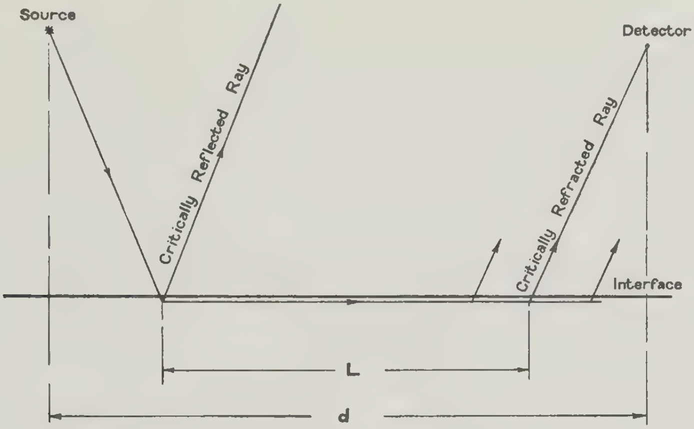

Fig. 1. The Critically Refracted Ray Path

THE FIELD EXPERIMENT

A refraction line was shot over the Eakring-Dukes Wood oilfield in the Midlands of England. The formational dip was known to be less than 1°. The main purpose of the survey was to obtain time–distance data, and conventional equipment was used in which a fairly high degree of filtering was incorporated. No A.V.C. was used and the amplifier gains remained constant throughout a record. After each shot, a 13 c.p.s. oscillator was placed across the inputs to the amplifiers and their outputs recorded at the end of the seismogram. This enabled galvanometer deflection on the seismic record to be converted into voltage input to the amplifiers. The line resistance between the geophones and the amplifiers was kept constant, so that, providing the geophones were of equal sensitivity, voltages measured on the record are directly proportional to ground motion at the geophones. The data presented here were obtained from first arrivals and their amplitudes were measured as the height of the first peaks in millivolts input at the amplifiers.

PRELIMINARY MEASUREMENTS

The relative sensitivities of the geophones were found by grouping them together in a specially prepared pit and measuring their outputs for a shot about 5,000 feet away. The measurements were normally distributed about the mean with a standard deviation of 4%. Also, shots at 15,000 feet distance were recorded with a spread of eight geophones ten feet apart, which was placed perpendicular to a line joining the shot hole to the centre of the spread. The measured amplitudes of the first peaks were scattered about a mean with a standard deviation of 10%. These variations must be due to near surface irregularities and to 'geophone plant', and although the arrival measured was not the one with which we shall be concerned, it is to be expected that the scatter on its amplitude will be much the same. Repeat shots fired on the same day gave almost identical results. Errors in scaling the peak heights are usually not more than 1 or 2%, but for the smaller amplitudes they may reach 15 to 20%. From these preliminaries we might therefore expect that individual amplitude measurements have an associated standard deviation of around 10% to 12%, most of this being due to the effect of near surface irregularities.

The refracted arrival is a pulse, and probably any attenuation over and above that due to the spread of the wavefront will be to some extent frequency dependent. It is quite likely, therefore, that the pulse shape will change with distance and that the measurement of first peak height may then bear no simple relation to the total energy in the pulse [1]).

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[1]) See, however, the work of Ricker (1943) and Knopoff (1956) in which it is shown that peak amplitude measurements in visco-elastic media may obey a simple power law at 'large' distances from the source.

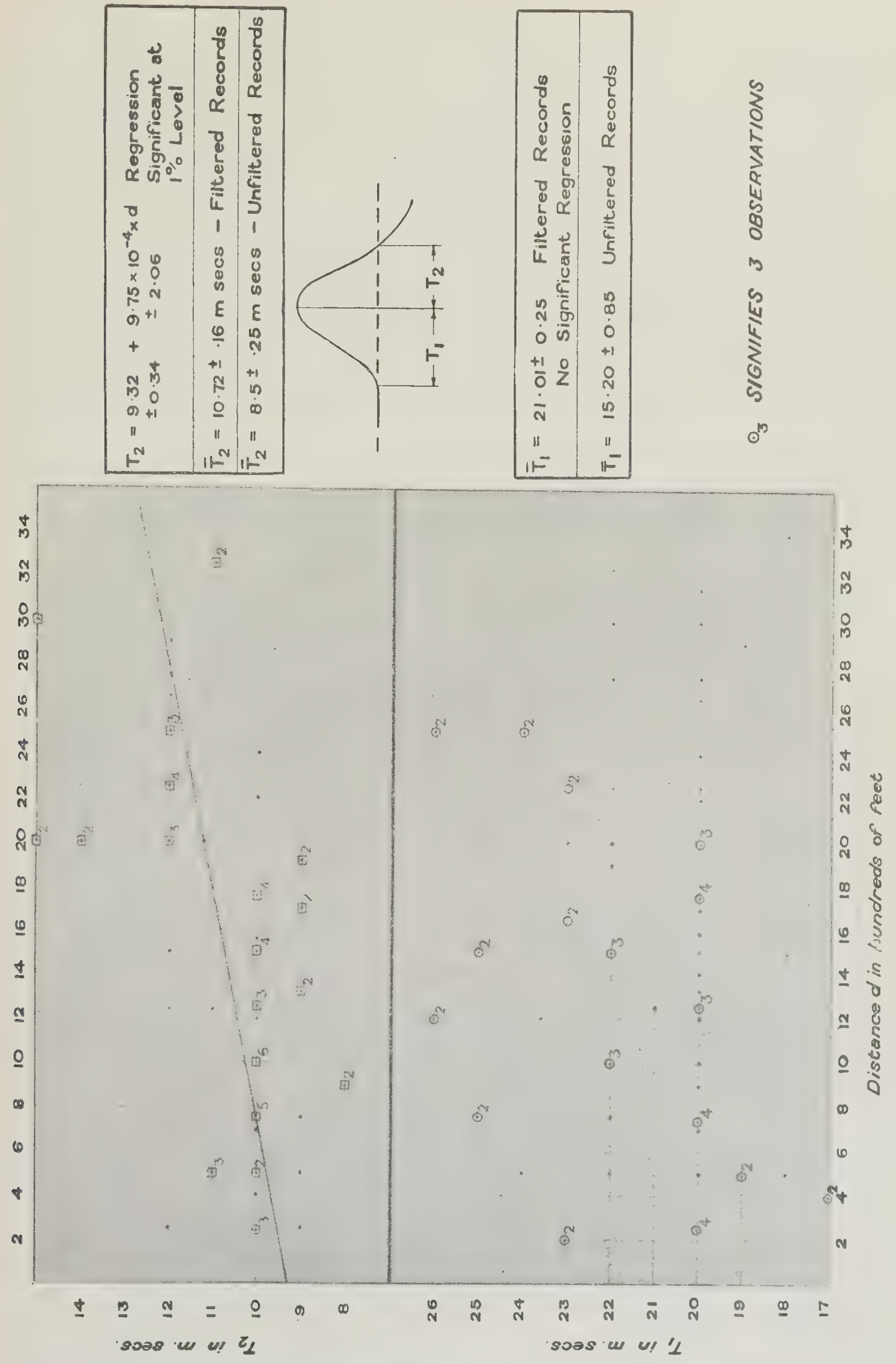


Fig. 2. Variation of Pulse Shape with Distance

It is not easy to say whether any change in pulse shape took place, for later arrivals usually interfered with the first arrival pulse. It was often possible, though, to measure the first and second 'quarter-periods' of the pulse and these were plotted against shot-detector distance as shown in figure 2. These data were taken from many records and much of the scatter is due to variations in shot-hole characteristics. However, it does seem possible that the pulse recorded broadened slightly with increase of distance from the shot. These records were obtained with a degree of filtering in the instruments which discriminated sharply against components much higher than about 10 c.p.s. In order to see whether this has any marked affect on the measured 'quarter-periods', a 12 station 3000' spread was shot with instrumental response flat from about 1 c.p.s. to 50 c.p.s. The values for T_1 and T_2 from these unfiltered records showed no significant ($> 10\%$ level) regression on distance but their values were significantly lower ($< 1\%$ level) than those from the filtered records. From these results it is therefore impossible to be sure whethei or not there was any appreciable amount of frequency dependent absorption.

THE EXPERIMENTAL DATA

The geophone stations were 250 feet apart and numbered from 1 to 72. The shot points were positioned close to stations 1, 22, 42, 62 and 72 and were lettered respectively A, B, C, D and E.

Amplitudes were obtained from four spreads, three of 5000 feet and one of 2500 feet. Each of them was shot from both ends. Figures 3-6 give the amplitude distance data for each shot together with the relevant time-distance graphs. Also tabulated in these figures are the reduced amplitudes after reducing each measurement to a standard distance of 2000 feet on the assumption that the 'spread' factor is $d^{-1/2}L^{-3/2}$. The values for L were found after the velocity-depth section had been deduced from the results of four 10 feet spacing refraction spreads and from the results of velocity surveys in three holes evenly spaced along the line. The velocity of the refracting horizon varies laterally from about 8000 feet per second to about 10,000 feet per second, and the velocity immediately above the refractor lies between 3000 feet per second and 5000 feet per second.

DISCUSSION OF RESULTS

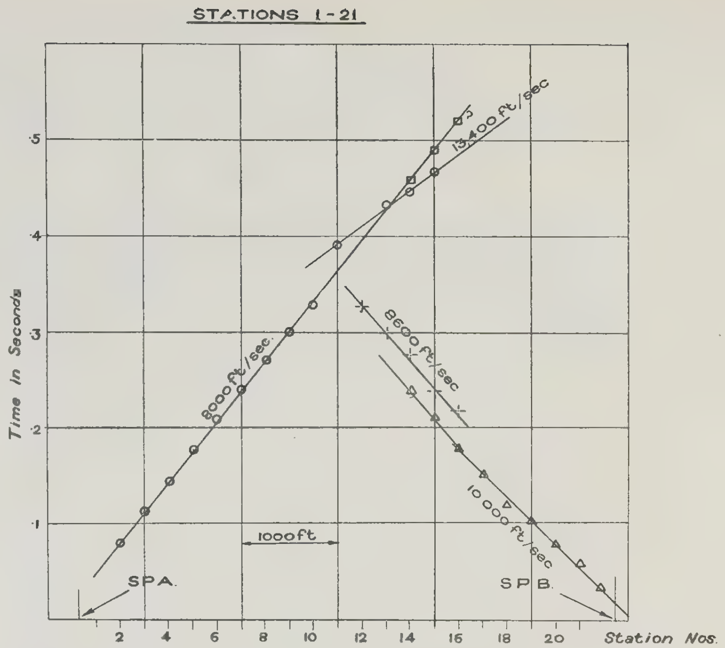
The amplitude measurements have been fitted by least squares to the formula

$$A = K/d^m$$

where A = amplitude,

d = horizontal distance between source and detector,

K, m = constants.



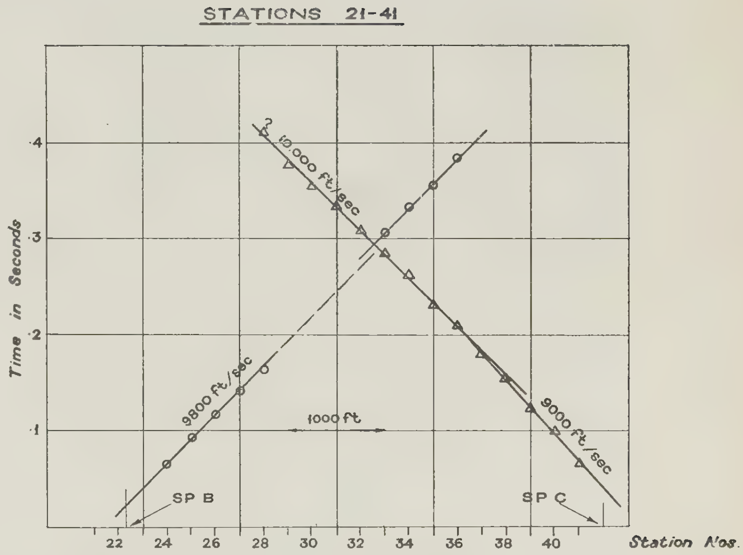
Station	2	3	4	5	6	7	8	9	10
Relative Amplitude	5·65	1·73	1·165	·625	·475	·340	·290	·139	-
Reduced Amplitude	·187	·168	·229	·208	·235	·192	·273	165	-

S.P. A.

Station	21	20	19	18	17	16	15	14
Relative Amplitude	10·59	5·22	1·635	·858	409	·254	·093	045
Reduced Amplitude	272	363	·249	·231	·173	·153	·078	·048

S.P. B.

Fig. 3 Time, Amplitude and distance data for stations 1–21



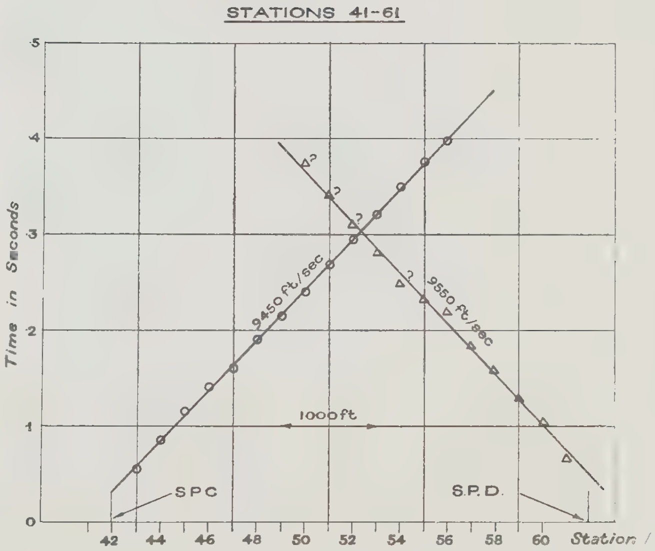
Station	24	25	26	27	28	29	30	31	32	33	34	35	36
Relative Amplitude	7·98?	5·53	3·45	1·87	1·34	-	-		·	·075	·076	·060	045
Reduced Amplitude	·266?	·534	·670	·612	·655	-	-	-	-	·134	·161	·149	·132

S.P. B

Station	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27
Relative Amplitude	>6	2·24	2·34	1·688	·893	·623	·266	194	·198	109	·089	·062	·048	·038	·020
Reduced Amplitude	-	·11	·30	·39	·34	·34	·20	·19	·25	·17	·17	·14	13	·12	·07

S.P. C.

Fig. 4 Time, Amplitude and distance data for stations 21—41



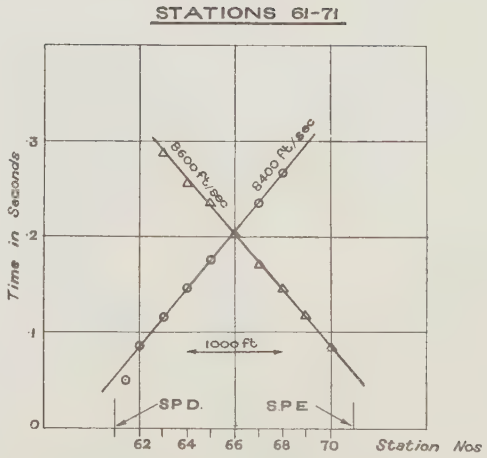
Station	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Relative Amplitude	0·08?	3·59?	2·88	1·56	·915	·725	·430	357	·231	·220	·121	·120	·062	·066	·060
Reduced Amplitude	11	·18?	·359	·361	·343	·398	·322	·357	293	·343	·230	·272	166	201	·212

S P. C

Station	61	60	59	58	57	56	55	54	53	52	51	50
Relative Amplitude	4·85?	2·70	1·39	1·01	·58	·395	·195	·131	·111?	·09?	·06?	·05?
Reduced Amplitude	·51?	·127	·166	23	·214	·204	·146	·131	·140	·144	·115	·113

S.P.D.

Fig. 5 Time, Amplitude and distance data for stations 41—61



Station	63	64	65	66	67	68	69
Relative Amplitude	1350	336	174	118	-	036	034
Reduced Amplitude	014	0 16	0.22	0.28	-	0.20	024

S P. D

Station	71	70	69	68	67	66	65	64
Relative Amplitude	1·704?	627	254	130	·090	052	·043	037
Reduced Amplitude	·018?	030	·031	·032	·034	·029	·032	·036

S P E.

Fig. 6 Time, Amplitude and distance data for stations 61—71

This formula has been used because it was found that the refractor is only about 80 feet deep and that consequently the factor $d^{1/2}L^{-3/2}$ quoted in the introduction will be very close to d^{2}. In fact it can be shown that for the depths and velocities involved a least squares fitting of d^{-m} to measurements following $d^{-1/2}L^{-3/2}$ will give a value for m of 2.03.

When there is a discontinuity in a time-distance graph the amplitude measurements either side of the discontinuity have been separately fitted to the inverse power formula.

Table I shows the results of the computations. They give a value of $2.16 \pm .04$ for m. This is in close agreement with the predicted value of 2.03. As will be shown later the slightly high value for m yields a reasonable value for refractor attenuation. The standard error associated with a single measurement as estimated by the least squares determination of m is about 8%. This should be compared with the estimates of 10% to 12% found from measuring the variation in geophone sensitivity and the effect of near surface irregularities.

TABLE I

S.P. / Stations	m	S.D. of m
A / 2- 9	2.06	0.12
B / 16-21	3.15	0.25
B / 25-28	1.94	0.15
B / 33-36	2.03	0.68
C / 27-35	3.24	0.09
C / 36-39	1.98	0.27
C / 45-57	2.49	0.10
D / 50-60	2.34	0.12
D / 63-69	1.93	0.09
E / 64-70	2.01	0.08

Values of m in the formula $A = K/d^m$

$\overline{m} = 2.16 \pm .04.$

Where there are discontinuities in the time-distance graphs, as in figure 4, there appear to be corresponding discontinuities in the plots of reduced amplitude. These discontinuities are not apparent in the uncorrected amplitudes as they are swamped by the variation due to the 'spread factor'.

Although the observations agree so closely with simple theory it may be as well to state the assumptions inherent in the analysis and to see how far they are fulfilled in the field. The physical conditions assumed are:

(i) The upper medium is extensive and of constant velocity.
(ii) The lower medium is extensive and of a constant velocity greater than that in the upper medium.
(iii) The two media rest in plane contact (slipless, if two solids).

(iv) The measurements are made at distances from the critically reflected ray which are 'great' compared with a 'wavelength'.
(v) There is no absorption or scattering of energy.

Condition (i)

This is violated on both counts. The velocity definitely increases with depth, though the increase is confined to the first 10 to 15 feet. From a consideration of physical principles it may be supposed that this will not matter providing the event measured is a true first arrival, and that the material immediately above the refractor is of constant velocity. Over the whole line there is some slight lateral variation in the overburden velocity, but this is extremely small and it would not be expected to effect the results for a single spread.

More important is the discontinuity produced by the earth's surface. Perkeris (1948) has given a very complete analysis for the case in which a surface layer overlies an extensive medium. He showed, that for points not too close to the source, the velocity potential (he was dealing only with liquids) could be divided into two parts. One is given by the evaluation of a sum of residues in the complex domain, and the other by evaluating a branch line integral. Both these parts predict waves travelling with the velocity of the lower medium. That due to the residues is the 'normal mode' solution in which the received pulse builds up from zero amplitude and consists of a long, dispersive train of waves which are both amplitude and frequency modulated; their potential varies inversely as their distance from the source. The branch line integral has been shown by Officer (1953) to give a 'multiply reflected refraction' with its amplitude also varying inversely as the distance. In contrast with the 'normal mode' arrival the 'multiply reflected refraction' has a sharp beginning, stays at a fairly constant amplitude and consists of a series of discrete frequencies given by the equation

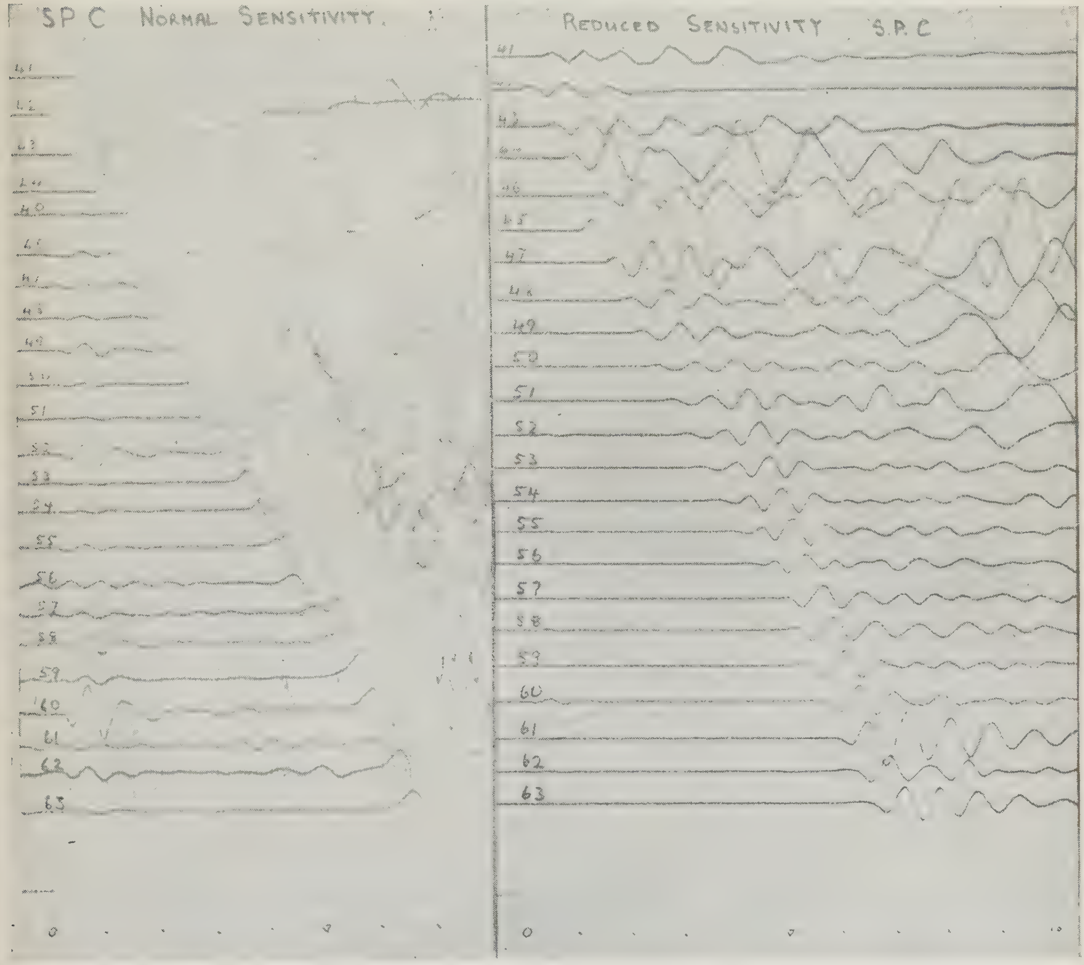
$$f = \{ (2n - 1)\, C_1 C_2 \} / \{ 4H\, (C_2^2 - C_1^2)^{\frac{1}{2}} \}$$

where n = an integer,
C_1 = velocity in the upper medium,
C_2 = velocity in the lower medium,
H = thickness of the surface layer.

Using this equation we find that for $n = 1$, $f = 15$ c.p.s. approximately. We should not expect to see any higher modes recorded because of the characteristics of the filter.

As may be seen in figure 7, the first arrival has a sharp beginning; it is therefore not a 'normal mode' event.

Judged from the first half period as recorded on the unfiltered record the ground motion has a predominant frequency of about 21 c.p.s. Unfortunately, owing to interference by later arrivals, it is not possible to say whether the peak measured is part of a long train, which might be expected on the multiple reflection hypothesis—or whether it is part of the relatively sharp pulse which would be expected if it was a 'critically refracted' event. The two records in figure 7 are of the same shot, the sole difference being that the one record was taken with amplifier outputs about one tenth of those for the other. From inspection of the lower seven traces in the higher sensitivity record it appears



[Fig. 7 Normal and Reduced Sensitivity Records for S.P.C. into stations 41—63 most likely that what sinuousness of character is present is due to the interference of two relatively short pulses travelling with differing velocities. Because of these observations, but also because the residual attenuation would be much too high if the spread factor was taken to be d^{1}, the event measured is assumed to be formed by simple 'critical refraction'.

Because the geophones were placed on the ground surface only a certain proportion of their motion is due to the incident wave. In our case the proportion depends mainly on the angle of approach of the incident energy, and it has been assumed that it is a constant.

Condition (ii)

The time-distance graphs show (e.g. figure 3, S.P. B) that there is an appreciable lateral variation in the refractor velocity, which appears to take place in rather sudden jumps. Surveys were made to a depth of about 350 feet in each of three widely separated holes and the vertical velocity of the refractor was found to be sensibly constant in each hole, but to differ from one hole to another. Figure 8 gives a velocity section, as found by a conventional survey in a well midway along the line. The predominant wavelengths in the pulse are probably about 400 to 500 feet, so they are therefore approaching twice the thickness of the refractor; unless we choose to ignore a 10% velocity reversal, in which case the total thickness is somewhat greater than a 'wavelength'. With the refractor not much greater in thickness than a wavelength we might expect that extra energy would be lost across its lower boundary, especially if there is a velocity reversal. This does not appear to have happened.

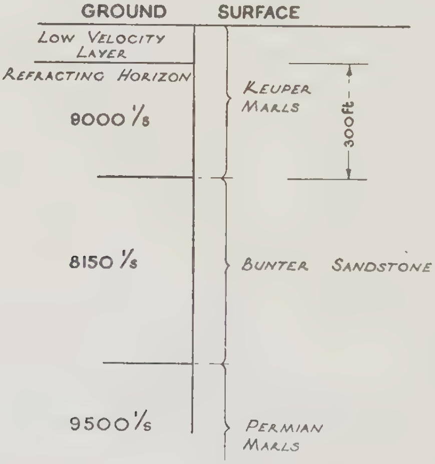


Fig. 8 Velocity - Depth Section from a well Survey

Condition (iii)

The time-distance graphs do not indicate any marked departure from a plane boundary, nor is any expected from known geology.

Condition (iv)

A study of the reduced amplitudes shows that the $d^{-1/2}L^{-3/2}$ factor seems to hold for distances at least as small as 1000 feet (about two "wavelengths" distance from the critically reflected ray). For smaller distances the reduced amplitudes tend to decrease as the shot point is approached which indicates that the observed amplitudes have been over-corrected. It may be remarked here that d^{-2} will be a rather better factor when L is small.

Condition (v)

Ignoring those measurements for distances less than about 1000 feet, the residual attenuation left after applying the $d^{1/2}L^{3/2}$ spread factor reaches a maximum of about 8 db per 1000 feet *), and has a mean of about 2.0 db per 1000 feet. This residual attenuation is no doubt largely due to absorption in the refractor, and is discussed further in the next section.

THE RESIDUAL ATTENUATION

In order to decide whether the reduced amplitudes better fitted an inverse power or an inverse exponential function, they were plotted on log-log and on semi-log paper and the graphs compared. There was not a decided advantage either way, but it did seem as if the inverse exponential function gave the better fit. Accordingly, table II gives the attenuation factors in decibels per 1000 feet as estimated by the method of least squares. Observations for distances less than about 1000 feet have been omitted. The mean value for all the determinations is 1.96 ± 0.28 decibels per 1000 feet.

TABLE II

S.P. / Stations	$\alpha = db/1000$ ft.	s.d. (α)
A / 3- 9	— 0.48	1.00
B / 16-19	7.84	1.58
B / 33-36	0.40	1.76
C / 27-35	4.10	0.84
C / 45-57	2.00	0.40
D / 54-58	5.24	0.96
D / 65-69	0.26	1.96
E / 64-68	— 0.72	0.68

Values for the residual attenuation

$\bar{\alpha} = 1.96 \pm .28\ db/1000'$.

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*) If A_1 and A_2 represent amplitudes $db = 20 \log_{10} (A_2/A_1)$.

Table III presents some values for residual attenuation which have been abstracted from the publications of other workers. The two very high values of 28 decibels per 1000 feet and 87 decibels per 1000 feet were obtained from field records of waves travelling direct from source to receiver over small distances. It seems probable that the first value was obtained for a pulse whose predominant frequencies were around 100 c.p.s.; if we assume that the attenuation is proportional to the first power of the frequency this would give a value of about 5-6 decibels per 1000 feet for a '20 c.p.s.' pulse. The high figure has already been reduced to allow for change of attenuation with frequency and it seems likely, therefore, that either the rock used was greatly affected by being close to the ground surface (perhaps by weathering and relief of pressure) or that the method of obtaining the attenuation is unreliable.

TABLE III

α = db/1000 ft.	Rock Type	Method	Predominant Frequency c.p.s.	Reference
1.8	Average of many	Conventional reflection	> 20	Fig. 9, Kendall, 1941
0.4	Dry shale	Vibration of cylinder	Reduced to 20 assuming α directly proportional frequency	Table I, Born, 1941
1.0	Mean for sandstone & limestone	- ditto -	- ditto -	Fig. 3, Bruckshaw & Mahanta, 1954
0.4	Dry sandstone	- ditto -	?	Table I, items 2a and 2b Sokoloff & Skriabin, 1937
8.0	The same sandstone wet	- ditto -	?	
6.0	Pierre shale	Field measurements of direct wave	Reduced to 20 c.p.s. by 'Ricker' theory	Ricker, 1949
0.2	Quincy Granite	Vibration of cylinder	Reduced to 20 c.p.s. assuming α directly proportional to frequency	Birch & Bancroft, 1938
0.5	Mantle	Long period Rayleigh waves	- ditto -	Ewing & Press, 1954
28	Shale	Field measurements of direct wave	About 100 ?	Graph 3, Pickett, 1955
87	Sandstone	- ditto -	Extrapolation to 20 c.p.s.	Fig. 6, Collins & Lee, 1956

Some published values of 'Residual' attenuation

It will have been noticed that many of the values in table III have been 'reduced' to a value for 20 c.p.s., whereas, in obtaining our value, frequency dependence has been ignored. In the section on "Preliminary Measurements" it was concluded that measurement of '$\frac{1}{4}$-periods' neither confirmed nor denied the possibility of frequency dependent attenuation, and in order to find out whether our value for residual attenuation was consistent with a linear dependence on frequency the following analysis was made. An amplitude-frequency spectrum was found for a typically shaped refracted pulse with a predominant frequency of 21 c.p.s. An attenuation of 0.8 decibels per wavelength was then applied for a distance of 3000 feet and the resulting spectrum compared with the original. The predominant frequency of the attenuated spectrum was found to be about 2 c.p.s. less than that of the original, and this would hardly be observable on our records. It may be pointed out here that if we assume the residual attenuation is proportional to the square of the frequency, then the predominant frequency in the pulse would drop from 21 c.p.s. to less than 10 c.p.s. over a 3000 feet spread, and this would most certainly have been visible on the records.

It seems, then, that the value of 1.96 decibels per 1000 feet is quite consistent with the observed '$\frac{1}{4}$-periods' provided that the residual attenuation does not have a dependence on frequency which is much greater than linear.

CONCLUSIONS

It is concluded that the theoretical 'spread factor' for critically refracted waves is correct and when applied to field refraction data a good estimate may be obtained for the attenuation of seismic waves due to the elastic imperfections of rocks. In any particular case, part of this 'residual' attenuation may be due to the scattering properties of the propagating medium as distinct from its departure from perfect elastic properties, though it is unlikely that scattering will be as serious a factor in refraction as in reflection work.

It has not been possible to detect any frequency dependence for the residual attenuation, largely because only the first half cycle of the pulse was undisturbed by later events. There are areas, however, in which the bulk of the refracted arrival may be observed, and it is hoped that records obtained in such areas will be used for attenuation studies.

One practical disadvantage in measuring amplitudes on seismic records is that the amplifying system in conventional equipment often has sharp filtering characteristics. With the gradual encroachment of broad band recording this disadvantage may soon disappear.

The value for the residual attenuation in a marl at about 80 feet depth, is found to be 1.96 ± 0.28 decibels per 1000 feet for a pulse whose predominant wavelength is about 400 feet.

ACKNOWLEDGEMENT

The author is indebted to the Chairman of the British Petroleum Company for permission to publish this paper, and to Mr. G. Bowling for performing most of the calculations.

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DISCUSSION

Mr. Meinhold: Soviet geophysicists assume to have found that the amplitudes ot refracted waves diminish with the thickness of the refracting layer owing to higher absorption. They could observe low velocity layers beneath high velocity layers distant from the shot. Have you observed something like that?

Mr. O'Brien: There is no doubt that as refractors get thinner the attenuation of the head wave increases greatly. And by observation of this rate of attenuation, together with the frequency content of the refracted pulse, it should be possible to obtain an estimate for the thickness of the refractor.

I have observed a pulse refracted from a lower velocity layer which lay beneath a higher velocity layer; but in that case the higher velocity layer was a thin (about 20 feet) band of limestone which lay on the surface and the shot was placed below the limestone. I have not observed this phenomena when both layers lie at some depth, but I am quite prepared to believe that such a thing is possible.

Mr. Evison: Mr. O'Brien is to be congratulated on having carried out these careful experiments in the difficult field of amplitude measurement. As he has suggested, we may confidently expect that practical techniques based upon variations of amplitude will eventually emerge.

Refracted waves are perhaps not the most suitable for providing measurements of absorption, since the attenuation due to expansion of the refracted wave front is so severe that, as in the present case, absorption is likely to provide but a small fraction of the whole. Regarding the statistical expression of results, this can be confusing: for example from the standard errors yielded by the two different analyses of the shallow refraction arrival one might ask whether the former alternative, neglecting absorption, were not the better of the two. Indeed the standard error expressed in $m = 2.16 \pm 0.04$ is so remarkably small that it seems possible that the absorption was negligible; in such a case there are various ways in which the value of m could exceed the theoretical $m = 2$, as for example by scattering from irregularities in the refracting interface, and such possibilities constitute a further drawback to using the refracted wave for absorption measurements.

Mr. O'Brien: Dr. Evison is undoubtedly correct in pointing out that the attenuation due to the expansion of the refracted wavefront is very high and, in the results presented in my paper, tends to swamp the attenuation due to all other causes. He has, indeed, underlined a major purpose of the paper which is to present field data confirming the theoretical d^{-2} factor for refracted waves.

That part of the attenuation in excess of d^{-2} is, of course, due to all the departures of the field conditions from the idealised theory, and includes the effects of scattering, heat dissipation, velocity gradient, etc., etc. In presenting this residual attenuation in *db*/wavelength I merely wished to point out that *if* it was all attributed to absorption the resulting figures would still be consistent with other published values.

I wished, by presenting this paper, to persuade others that it is possible to make useful attenuation studies with records obtained in routine surveys. If special experiments are to be made to measure rock absorption (and we badly need them) then probably it would be best to make measurements on the wave travelling direct from the source to the receiver, providing these are both *within* a uniform formation. I do feel, however, that reliable attenuation factors can be obtained from refraction records, especially as the ratio of the distances involved is not usually so great as they are for the results given in my paper.

SEISMIC MODEL EXPERIMENT ON THIN LAYERS*

BY

E. CARABELLI **) AND R. FOLICALDI **)

SUMMARY

Seismic two-dimensional model experiments have been made at the Laboratory of Fondazione Lerici in the Polytechnic School of Milan.

For this purpose the Laboratory has developed and constructed a complete equipment including pulse generators, piezoelectric transducers and amplifiers for detecting the waves propagation through the models.

We record here experiments concerning reflections from horizontal layers thin in relation to the wave lengths propagated through the media.

Layers, with a thickness from a 50th of the total wave length to several wave lengths were used. These strata consist of materials sometimes with lower and sometimes with higher velocities than the homogeneous surrounding medium.

The object of this investigation was to clarify the effects of the very thin reflecting layers, individually and in combination, on the reflected arrivals and to determine the influence of the layers upon the reflected energy in comparison with their thickness.

We are also studying at what minimum distance, as a fraction of the wave length, the reflection of a horizon appears on the seismogram in an independent event.

At the Laboratory of the Fondazione Lerici, Polytechnic School of Milan, a study has been carried out on seismic models in an attempt to investigate systematically some practical problems.

In order to make the laboratory experiments simulate field experiments on normal structures, we prepared a set of instruments suitable for authentic seismic tests, such as the determination of the propagation velocity through rock samples. Considerable difficulties were encountered in the realization of this equipment owing to the lack of suitable materials and of any previous experience in this field.

The instrumentation consists of pulse generators, piezoelectric transducers which transform the electric pulses into acoustical ones and vice versa, a video amplifier, supports for model, and finally a cathode-ray oscilloscope complete with time marker and camera.

For practical reasons, the study on the models was started with two-dimen-

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*) Presented at the Eleventh Meeting of the European Association of Exploration Geophysicists, held in Milan, 12-14 December 1956.

**) Fondazione Lerici, Politecnico di Milano.

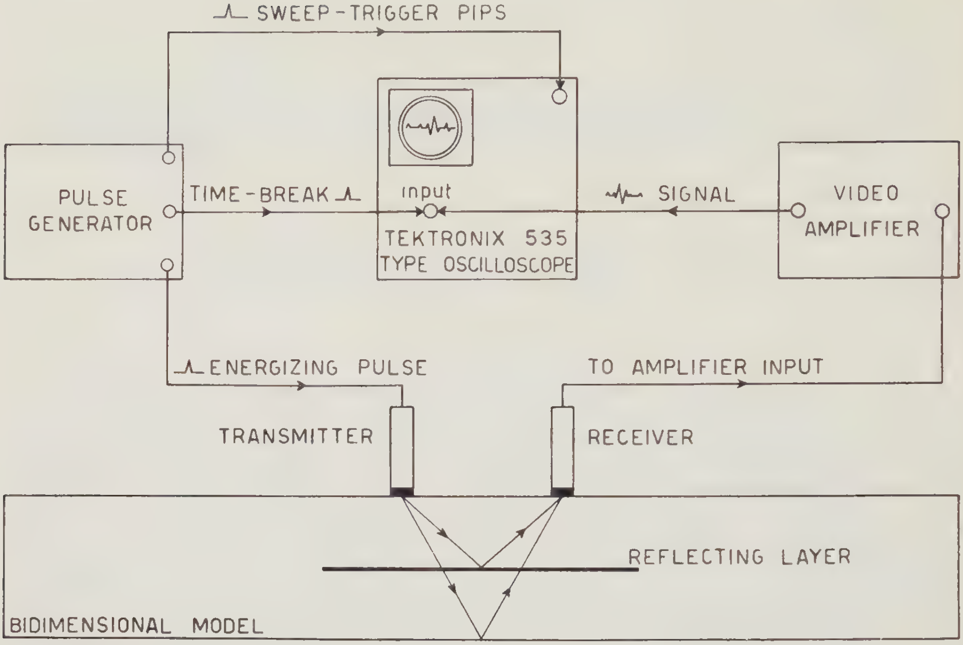

Fig. 1. Schematic diagram of apparatus

sional structures which, while allowing simplicity of construction and quickness of operation, gave results valid for three-dimensional models after making the slight theoretical modifications needed to transform the experimental data into the real three-dimensional case (Oliver, Press and Ewing, 1954).

So far, the only limitation which detracts from the application of the models to the general study of geological structures, is the difficulty of obtaining materials necessary for the simulation of multi-layer cases where the velocity and density ratios existing in nature between the various layers are reproduced.

The instrumentation includes a pulse generator which triggers the oscilloscope beam and produces the energizing pulse which is introduced on the trace as the time break.

The electrical excitation has a very rapid rise in about a tenth of a microsecond, a total length of about 5 to 10 microseconds and peak voltage adjustable from 750 to 2000 Volts.

The pulse repetition rate can be preset from 100 to 1000 p.p.s. Generally, a frequency of about 200 p.p.s. was employed with models having an average length of about 1.5 m.

The pulse generator is connected to the barium titanate transducer by means of coaxial cable.

The size of the ceramic part can be chosen from discs of 3 to 10 mm. diameter and of thickness 2 mm. The discs are joined with plastic cement to an aluminium or brass rod, having appropriate shape and length, and which acts as a damper and active electrode. This rod is mounted coaxial in a metallic insulated tube which shields completely the transducer. The lower face of the transducer is covered with a very thin aluminium foil.

The receiver is substantially similar to the transmitter, with the barium titanate diameter of minimum possible size.

The barium titanate discs are not commercially available in such small sizes and, after baking, they require special treatment to obtain the required sensitivity.

The receiving equipment consists of a video amplifier which includes some low cut-off stages to eliminate noise and audio frequencies.

In our model, normally, the pass-band goes from about 50 kc to several megacycles.

The video amplifier is connected with a Tektronix 535 type oscilloscope with a wide-band plug-in unit amplifier.

Some particular transducers, shaped as small ceramic cylinders and mounted within the sheet forming the model, can also be employed, but these are heavily damped.

Fig. 2 shows, at the left, the pulse generator, in the center the model in its wooden support with cotton wool packing which serves to damp out the flexural motion of the plate and, at the right, the receiving equipment.

The piezoelectric transducer can slide along the metal, acoustically insulated, track visible in the figure, to explore the model at any point.

The piezoelectric transducers are mounted in acoustically insulated supports and they can slide on the upper edge of the model. A thin layer of grease acts as an efficient coupling. These transducers are essentially accelerometers.

It is possible to vary their sensitivity with additional masses which also improve the efficiency of their contact with the model.

The models are made from sheets, 2 mm. in thickness, of aluminium, plexiglass, brass or bakelite, etc., allowing a range of velocity ratios to be built up. The various layers are connected with epoxy Araldit resin having an acoustical impedance similar to that of the plexiglass.

In the particular case of models having very thin layers, they are obtained by cutting a channel about 1 mm. wide. In the slots so obtained, resin of the required density or paraffin is then poured, taking care to avoid air bubbles. In this manner it is possible to obtain a very compact and homogeneous layered medium.

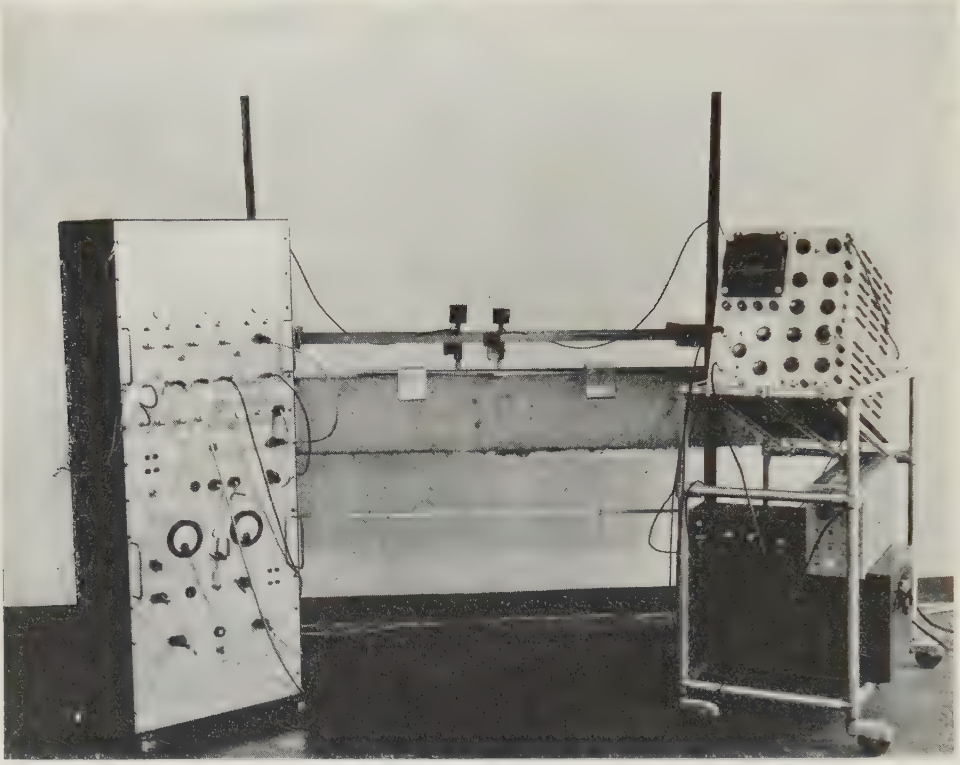

Fig. 2. Photograph showing experimental arrangement

In fig. 3 is shown the particular method of reading the arrival times by means of a light spot which can be moved along the trace using the time calibration system included in the Tektronix oscilloscope.

On the left the spot coincides with the time break, in the centre with the first arrival and, in the last, with the Rayleigh wave. This routine system virtually eliminates the necessity of a photo recorder and time marker and allows the experiments to be conducted rapidly. The photo recorder, therefore, is used exclusively for documentation work. Permanent records are obtained with a Du Mont camera arranged so that the 35 mm. film moves vertically by a small distance for each exposure. With a multiple exposure technique, employed by previous experimenters, it is possible to simulate all types of field seismograms.

The absence of extraneous disturbances on the records arises from the very efficient electrical shielding of the apparatus and from the damping of the model by the cotton filled cradle mounting. Particularly efficient is the

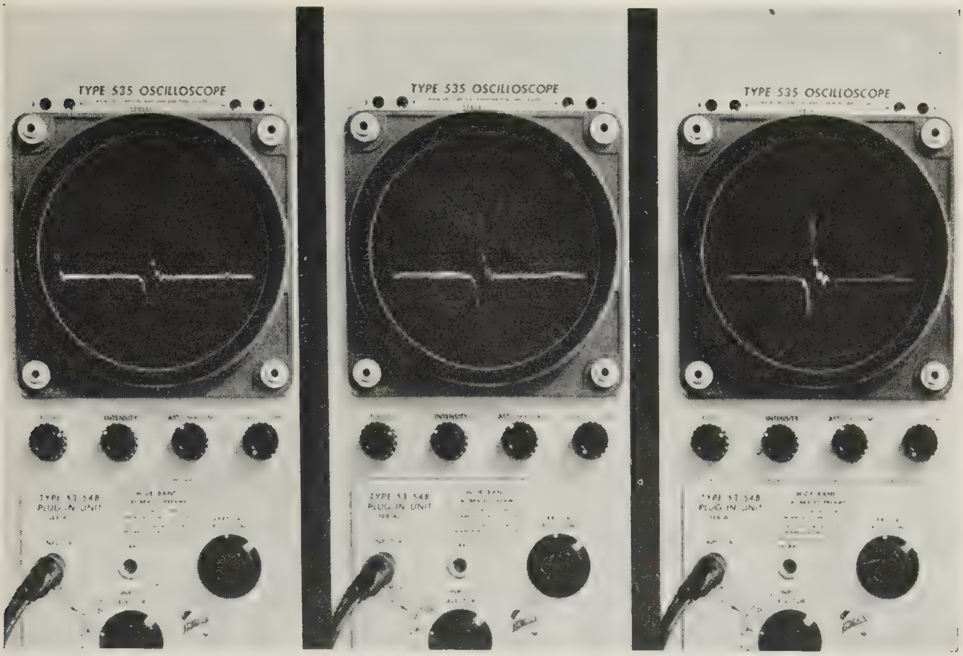

Fig. 3. Illustrating the use of the Tektronix oscilloscope to measure arrival time

damping of the barium titanate due to the aluminium or brass backing, which eliminates all spurious oscillations and ringing. Consequently the applied pulse is perfectly reproducible under the same conditions and the seismogram obtained on the oscilloscope screen remains unchanged over long periods of time.

We report here on some preliminary investigations using models having a thin layer structure within a homogeneous medium. Layers were used having velocities both higher and lower than the surrounding medium. These experiments, in addition to serving as a test of the equipment, were designed to determine a) whether very thin layers could give rise to reflections of detectable amplitude, b) whether multiple layers would give reflections which could be resolved on the seismogram and c) in the case of positive reflections, what is the minimum distance between layers allowing a resolution of the reflections. The possibility of determining the thickness of the layer was examined in the case of layers having high velocities and densities, and where the thickness was equal to a wave length or less. These investigations were partly suggested by the experience in certain practical cases, i.e. the problems encountered in the search for sulphur deposits where thin limestone layers were separated by clay beds. Layers were used with a thickness varying from a small fraction of a wave length to values slightly greater than a wave length.

Figure 4 presents the seismograms obtained on an aluminium model with the interposition of three Araldit resin layers having a thickness of 1 mm. and a separation of 30 and 60 mm. respectively.

The vertical dimension of the model was 500 mm. and the depths of the layers were 350, 320, 290 mm. respectively. The velocity of the longitudinal wave in the plate was 5600 m sec.^{-1} for the aluminium and 2200 m sec.^{-1} for the resin.

Besides the first arrival and the S waves interfering with Rayleigh wave, reflections are recorded from the layers and from the base, these including both multiple and transformed reflections. In any case, the layers are easily separated on the seismogram. The large amplitude of the Rayleigh wave is worth noting.

Fig. 5 shows a further series of seismograms registered on the same model. In this case, the shot point was placed vertically above the edges of the layers. The particular configuration generates on the seismogram a sequence of pulses due to diffraction at the end of the layer, giving pulses which can easily be mistaken for a reflection from a ghost layer. This effect, similar to the one generated by a fault, is very clear in the last seismogram at the right, where the ghost reflection has a large amplitude which interferes with the reflection from the underlying layer.

Fig. 6 refers to a plexiglass model having $V_p = 2350$ m sec.^{-1}, with two thin layers, the upper layer being of Araldit and the lower, for simplicity, of air. Each layer has a thickness of 1 mm. and they were separated by 10 and 5 mm. respectively in the two cases. The first layer was at a depth of 150 mm. It is clearly noticeable that the interference of the reflection coming from the two layers progresses as the distance between them decreases. The transformed *PS* reflection and the multiple reflections can also be observed.

In the second case with the closer layers their separation was about 1/6 of a wave length.

Fig. 7 represents the case of plexiglass model with high velocity aluminium layers. For the plexiglass, $V_p = 2350$ m sec.^{1} and the density $= 1.22$ gm/cm^3 and for the aluminium, $V_p = 5600$ m sec.^{-1} and the density $= 2.7$ gm/cm^3; the acoustical impedance ratio is therefore 5.2 to 1. Two cases with layers having thicknesses of 40 and 10 mm. are shown, changing from about 3/4 of the aluminium wave length to about 1/5 of the wave length.

In the first picture we see the reflection from the upper face of the layer followed by the reflection from the lower face, the latter having a small amplitude on account of the high acoustical impedance ratio. In the second figure the reflection from the lower face interferes with that from the upper face and it is possible to separate it only for the greater angles of incidence. The depth of the layer was 400 mm., the spread is symmetrical and has a

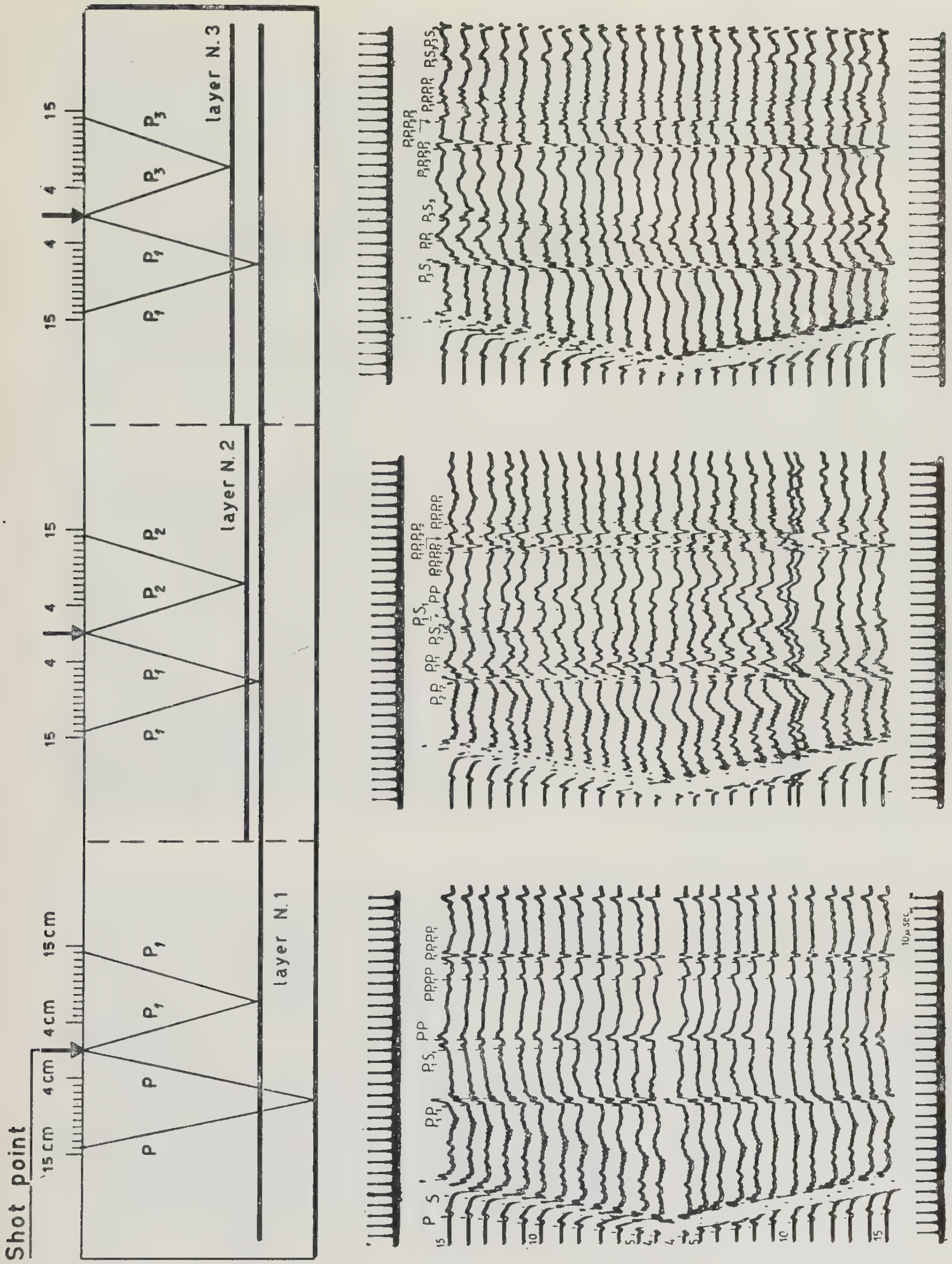

Fig. 4. Two dimensional aluminium model

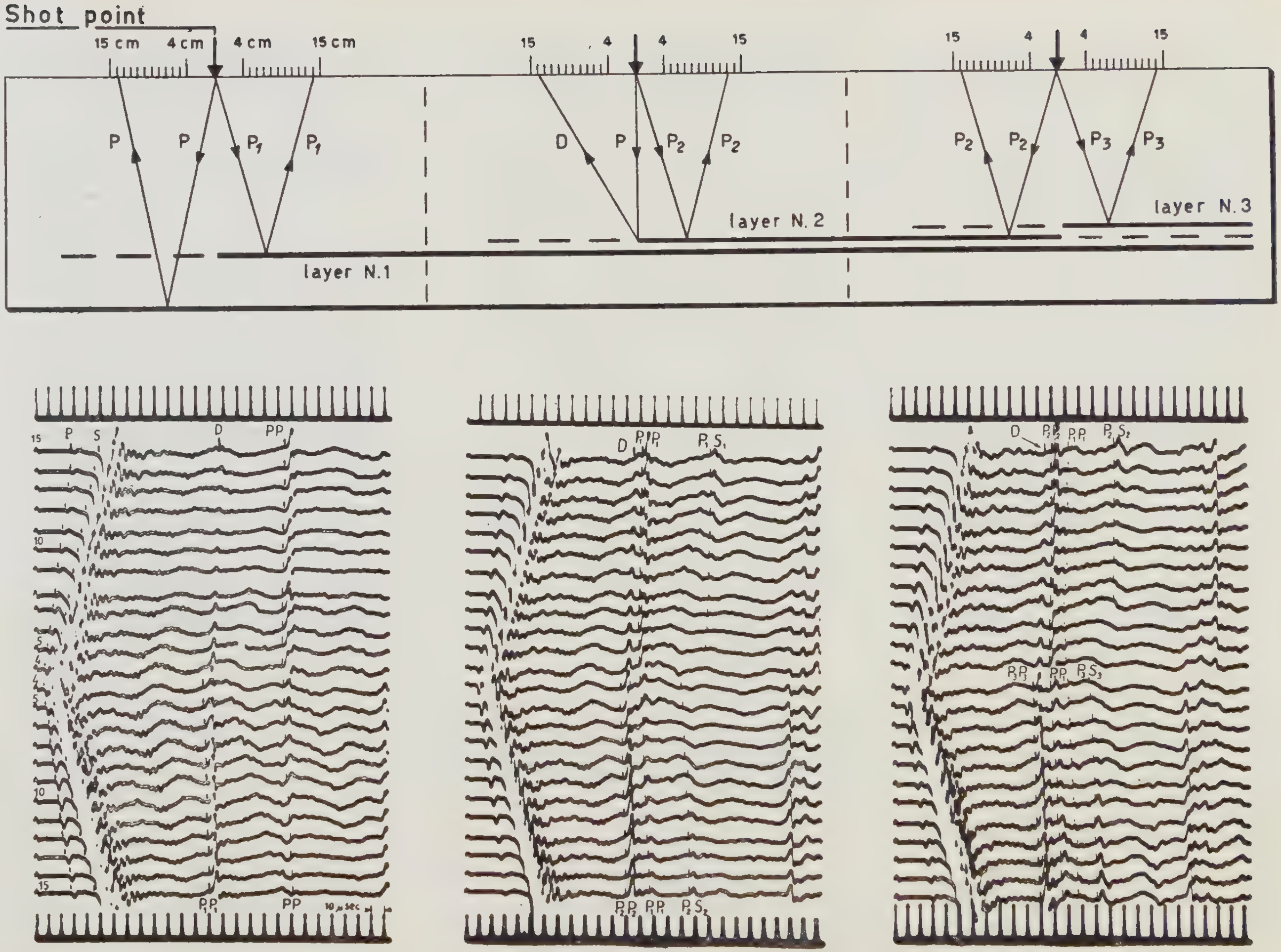

Fig. 5. Two dimensional aluminium model

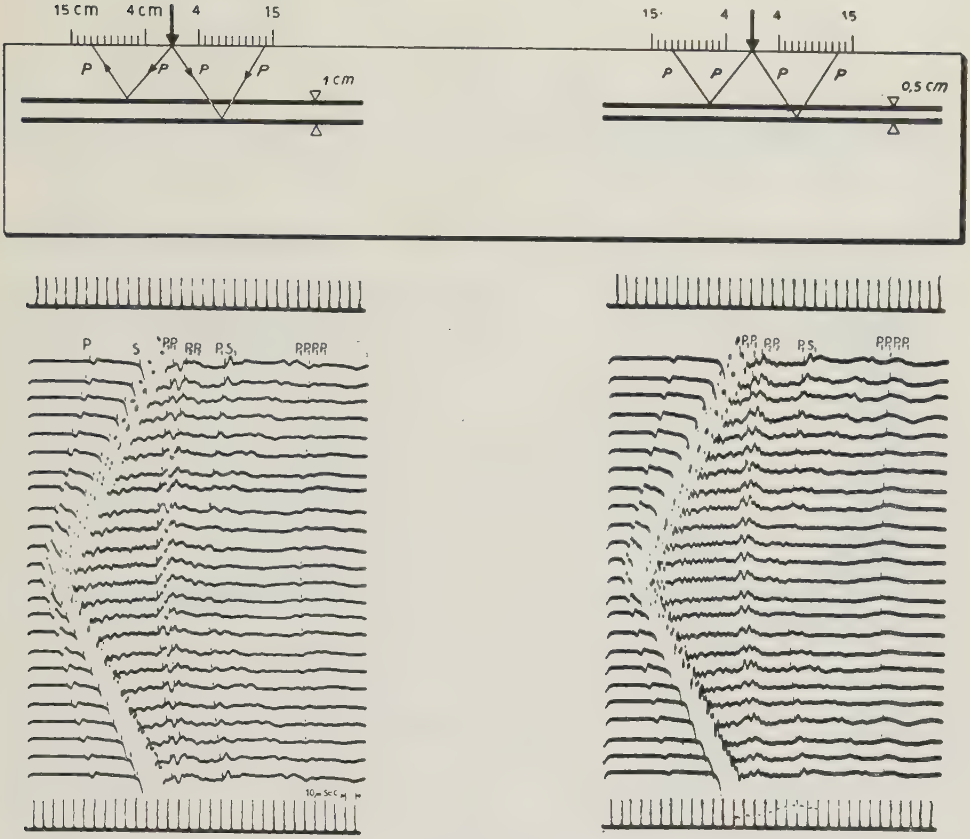

Fig. 6. Two dimensional plexiglas model with araldit layers

half-length of 150 mm. Hence, only for distances of about a quarter of the depth can we separate the arrivals.

To obtain an idea about the distribution of the seismic intensities in the model, for each type of waves we have plotted the recorded amplitude of the seismic arrivals with a fixed amplification as a function of the incident angle of the ray. This is equivalent to recording a quantity proportional to the acceleration of the point at which is placed the transducer.

Because the intensity I is given by

$$I = \omega^2 A^2,$$

where ω = frequency, a constant for each wave,
and A = displacement amplitude,
and since $a = A\omega^2$, when a is the acceleration of the point,

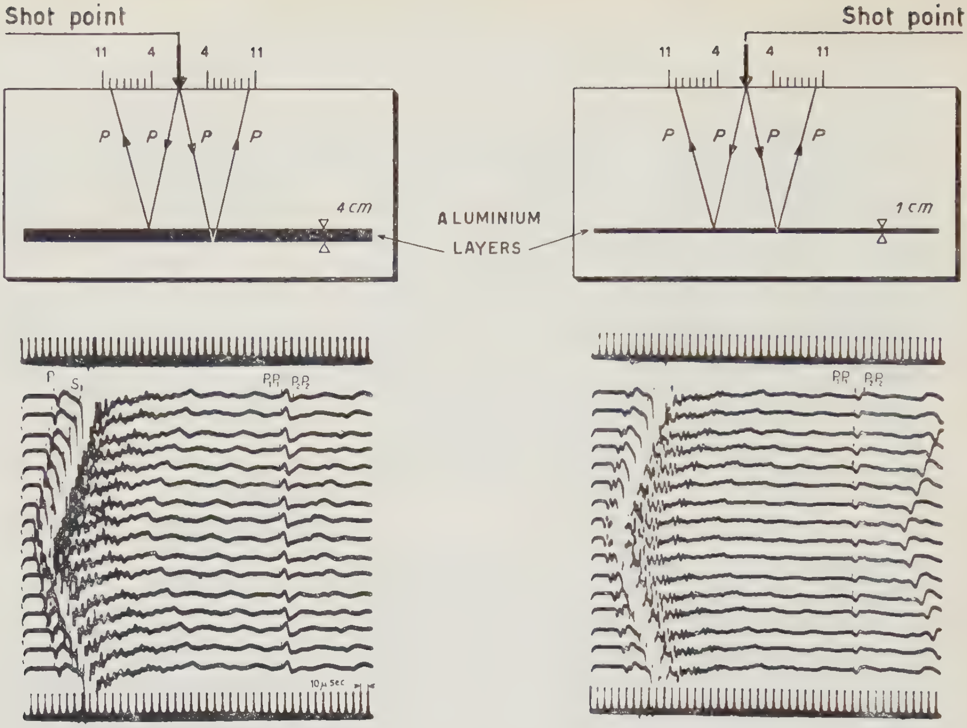

Fig. 7. Two dimensional plexiglas model with aluminium layers

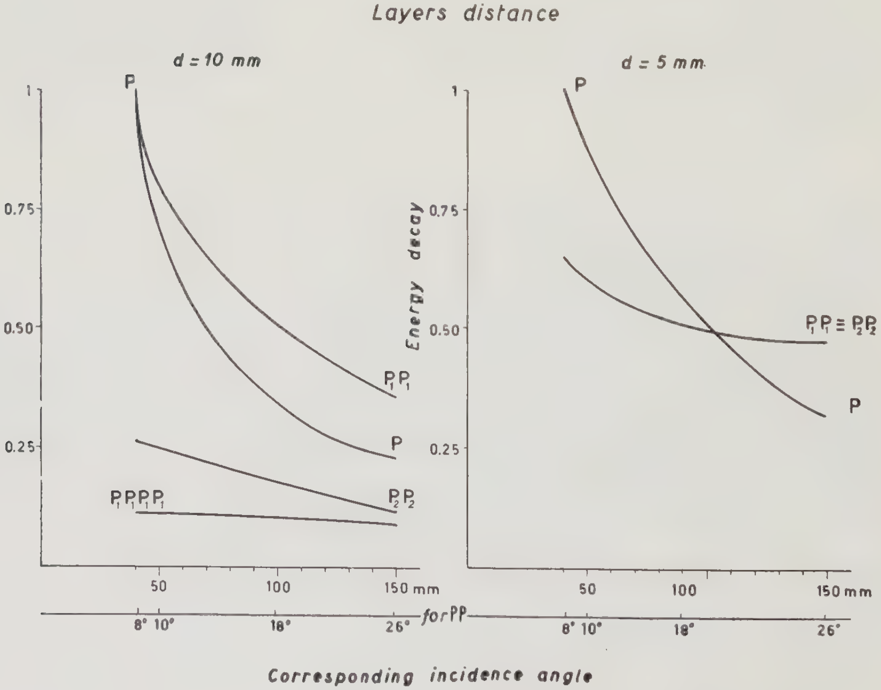

Fig. 8. Wave amplitudes on plexiglas model with araldit layers (see Fig. 6)

then $a = \sqrt{I\omega^2}$,
and $I = a^2$ (for ω = constant).

The curves in fig. 8, obtained using an average of several readings, give the relative variation of the energy received at the various points in the model· We have taken as unit energy the energy of the P wave at the nearest point to the transmitter (40 mm.).

Conclusions

Although the present experiments served mainly to adapt and develop an experimental technique for model seismic problems which would be difficult to solve theoretically or in the field, some valuable results were obtained from the series of tests.

Above all it was proved that very thin layers are capable of giving reflections of remarkable amplitude even in the case of moderated acoustical impedance ratios between the layer and the surrounding medium.

The phenomena, related to the diffraction at the edge of the layer, appeared evident and so also did the possibility of separating on the seismogram the various layers separated by a fraction of the wave length.

About the problem of determining the thickness of layers of high velocity density immersed in a low velocity medium, owing to the great damping both of the receivers and of the energizing pulses, the reflections appear as short pulses in contrast with field observations, where the arrivals present an oscillatory character. Thus, the separation of the arrivals on the model is simplified.

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THEORETISCHE UNTERSUCHUNGEN ÜBER DEN EINFLUSS DER VERWITTERUNGSSCHICHT AUF DAS SPEKTRUM ELASTISCHER WELLEN IN DER REFLEXIONSSEISMIK

VON

HEINZ MENZEL *) UND OTTO ROSENBACH **)

ABSTRACT

The following assumptions are made in the mathematical treatment of the problem. Below a plane earth's surface there is a three-layered elastic medium the interfaces of which are parallel to the earth's surface. The uppermost layer represents the weathered layer in which the velocity of propagation of seismic waves increases linearly with depth. The two lower layers, the so-called intermediate layer and the substratum each have a constant velocity. The surface of the earth is acted on simultaneously by a normal pressure N in the form of a Heaviside pulse. The seismic wave thus generated is propagated through the elastic media.

The aim of the investigation is to study the shape of the wave

1) in the intermediate layer, after the wave has entered it the first time,
2) at the earth's surface, after the wave has been reflected once at the interface between the intermediate layer and the substratum.

The mathematical solutions can in both cases be expressed as series of Bessel functions. Some numerical examples illustrate the quasi-periodic nature of the solutions. The pseudo-frequency is determined by the gradient of velocity in the uppermost layer; it assumes a value of approximately 50 c.p.s. for a gradient of appr. 600 $\frac{m/\text{sec.}}{m}$

ZUSAMMENFASSUNG

Für die mathematische Behandlung des Problems werden folgende Voraussetzungen gemacht: Unterhalb einer ebenen Erdoberfläche liegt ein dreischichtiges elastisches Medium, dessen Trennflächen der Erdoberfläche parallel sind. Die oberste Schicht stellt das Modell einer Verwitterungsschicht dar, in der die Fortpflanzungsgeschwindigkeit seismischer Wellen linear mit der Tiefe ansteigt. In den beiden folgenden Schichten, der sogenannten Zwischenschicht und dem Halbraum sind die Geschwindigkeiten jeweils konstant. Ein Normaldruck N in Gestalt einer Heaviside-Funktion, der simultan an der gesamten Erdoberfläche wirkt, erregt eine ebene seismische Welle, die sich in das elastische Medium hinein fortpflanzt.

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Ziel der Untersuchung ist das Studium der Gestalt der Welle

1) in der Zwischenschicht, nachdem sie erstmals in diese eingetreten ist,
2) an der Erdoberfläche, nachdem sie einmal an der Trennfläche zwischen dem Halbraum und der Zwischenschicht reflektiert worden ist.

Die mathematische Behandlung liefert in beiden Fällen als Lösungen Reihen von Besselfunktionen. Einige numerische Beispiele veranschaulichen die quasi-periodische Natur der Lösungen. Die Pseudo-Frequenz der Wellen wird vom Gradienten der Geschwindigkeit in der obersten Schicht bestimmt; es ergibt sich eine Pseudo-Frequenz von ca. 50 Hz, wenn der Gradient einen Wert von ca. 600 $\frac{\text{m/sec}}{\text{m}}$ hat.

1. EINLEITUNG

Bekanntlich dominiert im Spektrum der Wellen, die in der Reflexionsseismik beobachtet werden, der Bereich um etwa 50 Hz. Für diese Erscheinung gibt es noch keine ausreichende theoretische Erklärung. Insbesondere sind alle Versuche unbefriedigend geblieben, in denen man die Abweichungen vom ideal elastischen Verhalten dafür verantwortlich machte.

In der vorliegenden Untersuchung soll nun der Einfluss der Verwitterungsschicht auf das Spektrum seismischer Wellen studiert werden. Es ist bekannt, dass in der Verwitterungsschicht die Fortpflanzungsgeschwindigkeit der seismischen Wellen sehr stark mit der Tiefe ansteigt, d.h. dass sich in ihr die elastischen Parameter mit der Tiefe ändern. Daher wird für die Rechnung als theoretisches Modell der Verwitterungsschicht ein Medium gewählt, in dem sich die elastischen Parameter nach einem speziellen Gesetz stetig mit der Tiefe ändern. — Das Studium des Spektrums seismischer Wellen in einem derartigen Medium mit Hinblick auf den Versuch einer Erklärung der eingangs erwähnten Selektion des Frequenzbandes um 50 Hz ist durchaus sinnvoll, wie sich sofort aus der folgenden qualitativen Überlegung ergibt: Das Medium, dessen elastische Parameter sich stetig mit der Tiefe ändern, kann nämlich als der Grenzfall eines solchen angesehen werden, das aus vielen dünnen, horizontal gelagerten Schichten zusammengesetzt ist, deren elastische Parameter jeweils konstant, aber von Schicht zu Schicht verschieden sind. In dem geschichteten Medium treten durch Interferenzen, die auf Reflexionen und Brechungen an den einzelnen Schichtgrenzen zurückzuführen sind, erhebliche Änderungen des Spektrums einer seismischen Welle auf. Entsprechende Änderungen des Spektrums sind also auch im Grenzfalle des Mediums mit stetig veränderlichen elastischen Parametern zu erwarten.

2. PROBLEMSTELLUNG

Der Untersuchung liegt ein dreischichtiges elastisches Medium zugrunde, dessen Daten in Fig. 1 bildlich dargestellt sind. Die Erdoberfläche sei eine horizontale Ebene, in ihr liege der Ursprung eines rechtwinklig-kartesischen Koordinatensystems mit senkrecht nach unten gerichteter z-Achse. Bis zur Ebene $z = H$ reicht eine Deckschicht, die das Modell der Verwitterungsschicht darstellen soll. Es folgt eine Zwischenschicht bis zum (ebenen) reflektierenden Horizont bei $z = T$, an den sich sodann ein Halbraum anschliesst.

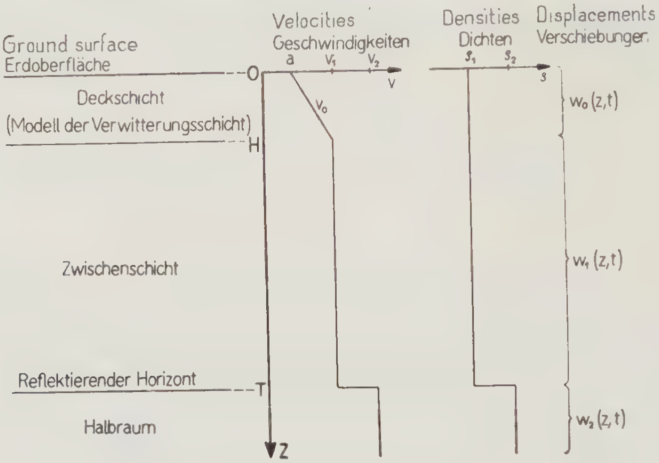


Fig. 1. Vorausgesetzte Daten über das elastische Medium.
Assumptions concerning the elastic medium.

In der Deckschicht wie auch in der Zwischenschicht sei die Dichte konstant und gleich ρ_1. Für die elastischen Parameter in der Deckschicht gelte

$$\lambda + 2\mu = \rho_1 (a + \delta z)^2 \qquad (1)$$

mit

$$\delta = \text{const} > 0.$$

Für die Geschwindigkeit der Kompressionswellen in der Deckschicht gilt also:

$$v_0 = v_0 (z) = a + \delta z; \qquad O \leqq z \leqq H, \qquad (1a)$$

d.h. die Geschwindigkeit nimmt linear mit der Tiefe zu 1)). In der Zwischenschicht soll die Wellengeschwindigkeit v_1 konstant sein und stetig an v_0 anschliessen:

1)) Es ist wenig wahrscheinlich, dass die Wellengeschwindigkeit in der Verwitterungsschicht durch das sehr einfache Gesetz (1a) dargestellt werden kann. Dieses Gesetz wurde angenommen, um die Schwierigkeiten der mathematischen Berechnung möglichst gering zu halten. Allerdings haben kürzlich angestellte, aber noch nicht abgeschlossene Messungen das Ergebnis geliefert, dass ein konstanter Geschwindigkeitsgradient in den obersten Schichten des Diluviums recht oft auftritt.

$$v_1 = v_0\,(H) = a + \delta\, H \tag{2}$$

Mit dem Übergang in den Halbraum findet bei $z = T$ ein Dichtesprung von ρ_1 auf $\rho_2 = \mathrm{const}$ sowie ein Geschwindigkeitssprung von v_1 auf $v_2 = \mathrm{const}$ statt.

An der Erdoberfläche wird eine Kompressionswelle durch einen Normaldruck $N(t)$ erzeugt, der simultan in der ganzen Ebene $z = O$ wirkt und überall von gleicher Grösse ist. Sein zeitlicher Verlauf soll gemäss Fig. 2 durch einen Rechteckimpuls dargestellt werden:

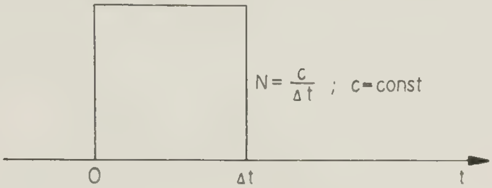


Fig. 2. Zeitlicher Verlauf des angenommenen Normaldruckes N, der an der Erdoberfläche simultan wirkt.
Normal pressure N, acting, as assumed, simultaneously on the surface of the earth, as a function of time.

$$N(t) = \begin{cases} o & \text{für} \quad t < o \\ N = \dfrac{c}{\Delta t} & \text{,,} \quad o < t < \Delta t \\ o & \text{,,} \quad \Delta t < t \end{cases} \tag{3}$$

wobei $c = \mathrm{const}$. Später soll $\triangle t$ gegen Null streben; durch (3) ist N so gewählt, dass

$$\lim_{\triangle t \to o} N \triangle t = c \tag{3a}$$

Es wird also eine sogenannte Heaviside-Funktion betrachtet. Die angenommene Art der Wellenerzeugung stellt einen idealisierten Fall des Poulter-Schiessens dar. Das Zeitgesetz des Impulses wurde einerseits aus Gründen der Einfachheit als Heaviside-Funktion gewählt; andererseits sollte aber ein Gesetz angenommen werden, durch das im Spektrum der erzeugten Welle nicht schon am Beginn eine dominierende Frequenz bestimmt wird.

Die durch den Normaldruck $N(t)$ an der Erdoberfläche erregte Kompressionswelle pflanzt sich in das dreischichtige elastische Medium der Fig. 1 fort. Sie wird auf ihrem Wege an den Ebenen $z = H$ und $z = T$ jeweils in reflektierte und gebrochene Anteile aufgespalten; trifft ein Anteil auf die Erdoberfläche $z = O$, so wird er dort reflektiert. Unsere Untersuchung ist nun nicht darauf ausgerichtet, den zeitlichen Ablauf der Bewegung in jedem Punkte des elastischen Mediums anzugeben; vielmehr hat sie die beiden folgenden speziellen Ziele:

1) Studium der Welle in der Zwischenschicht, nachdem sie die Deckschicht durchlaufen hat.

2) Studium der Welle an der Erdoberfläche, nachdem sie einmal am Horizont $z = T$ reflektiert worden ist.

3. DIE DIFFERENTIALGLEICHUNGEN UND DIE RANDBEDINGUNGEN DES PROBLEMS

Die im Abschnitt 2 gemachten Annahmen haben es zur Folge, dass nur eine Kompressionswelle entsteht und dass diese nur eine z-Komponente der Verschiebung besitzt. Die Verschiebung werde gemäss Fig. 1 in der Deckschicht mit $w_0\,(z, t)$, in der Zwischenschicht mit $w_1\,(z, t)$ und im Halbraum mit $w_2\,(z, t)$ bezeichnet.

In der Deckschicht gilt die Differentialgleichung

$$\rho_1 \, \frac{\partial^2 w_0}{\partial t^2} = \frac{\partial}{\partial z} \left[(\lambda + 2\mu) \frac{\partial w_0}{\partial z} \right] ; \tag{4}$$

daraus folgt mit Benutzung von (1):

$$\frac{\partial^2 w_0}{\partial t^2} = (a + \delta z)^2 \frac{\partial^2 w_0}{\partial z^2} + 2\delta \, (a + \delta z) \frac{\partial w_0}{\partial z} \, . \tag{4a}$$

Weiterhin gilt in der Zwischenschicht

$$\frac{\partial^2 w_1}{\partial t^2} = v_1{}^2 \, \frac{\partial^2 w_1}{\partial z^2} \tag{5}$$

und im Halbraum

$$\frac{\partial^2 w_2}{\partial t^2} = v_2{}^2 \, \frac{\partial^2 w_2}{\partial z^2} \tag{6}$$

Die Randbedingungen lauten:

$$\rho_1 \, a^2 \, \frac{\partial w_0}{\partial z} + N(t) = o \qquad \text{für } z = O \tag{7}$$

$$w_0 = w_1 \text{ und } \frac{\partial w_0}{\partial z} = \frac{\partial w_1}{\partial z} \qquad \text{für } z = H \tag{8}$$

$$w_1 = w_2 \text{ und } \rho_1 \, v_1{}^2 \, \frac{\partial w_1}{\partial z} = \rho_2 \, v_2{}^2 \frac{\partial w_2}{\partial z} \qquad \text{für } z = T \tag{9}$$

Die zweite Randbedingung in (8) ist deshalb einfacher als die entsprechende in (9), weil Dichte und Wellengeschwindigkeit in der Schichtgrenze $z = H$ als stetig, in der Schichtgrenze $z = T$ jedoch als unstetig vorausgesetzt sind.

4. DIE WELLE IN DER ZWISCHENSCHICHT NACH IHREM DURCHGANG DURCH DIE DECKSCHICHT

Zunächst betrachten wir nur die Welle, die nach ihrem Lauf durch die

Deckschicht erstmalig in die Zwischenschicht eingetreten ist. Hierfür sind die Gleichung (6) und die Randbedingung (9) nicht erforderlich.

4.1 *Formale Lösung.* Zur Lösung der Differentialgleichungen (4a), (5) mit den Randbedingungen (7), (8) dienen folgende Ansätze:

Für die Bearbeitung unseres Problems wird der Normaldruck $N(t)$ durch ein Fourier-Integral

$$N(t) = \int_{-\infty}^{+\infty} C\,(\omega)\, e^{i\omega t}\, d\,\omega \tag{10}$$

dargestellt, wobei die Fourier-Amplitude $C(\omega)$ sich mit Hilfe von (3) errechnet zu

$$C(\omega) = \frac{ci}{2\,\pi\,\omega\,\Delta\,t}\left(e^{-i\omega\Delta t} - 1\right). \tag{11}$$

Diese explizite Gestalt von $C(\omega)$ wird erst in einem späteren Stadium der Rechnung tatsächlich benutzt. Bis dahin kann in den nachstehenden Formeln $C(\omega)$ ohne weiteres auch als Fourier-Amplitude eines geeigneten anderen Normaldruckes angesehen werden, dessen zeitlicher Verlauf also von demjenigen in (3) abweicht.

Die obige Darstellung (10) des Normaldruckes $N(t)$, der den Wellenvorgang erregt, wurde deshalb gewählt, weil als Lösung für die Differentialgleichung (4a) der Integralansatz

$$w_0\,(z,t) = \int_{-\infty}^{+\infty} [A_0\,(\omega)\, e^{n_1\, ln\, \zeta} + B_0\,(\omega)\, e^{n_2\, ln\, \zeta}]\, e^{i\omega t}\, d\omega \tag{12}$$

zu machen ist, wobei

$$\zeta = \zeta\,(z) = 1 + (\delta/a)\, z \tag{13}$$

und

$$n_{1,2} = -\tfrac{1}{2}\,[1 \pm i\,\sqrt{(2\omega/\delta)^2 - 1}] \tag{14}$$

bedeuten. Man überzeugt sich leicht durch Differentiation, dass der Integrand von (12) ein partikuläres Integral von (4a) ist, so dass also auch das Integral über die Frequenz ω der Differentialgleichung genügt.

Entsprechend ist als Lösung von (5) das Integral

$$w_1\,(z,t) = \int_{-\infty}^{+\infty} [A_1\,(\omega)\, e^{i\,\omega\,(t - z/v_1)} + B_1\,(\omega)\, e^{i\,\omega\,(t + z/v_1)}]\, d\,\omega \tag{15}$$

anzusetzen. Da w_1 die aus der Deckschicht austretende, in der positiven z-Richtung wandernde Welle darstellen soll, ist

$$B_1(\omega) = 0. \tag{15a}$$

Geht man mit den Ansätzen (10), (12), (15), (15a) in die Randbedingungen (7), (8) ein, so erscheinen letztere als drei Integrale, die für beliebige Werte von t, $a > 0$, $\delta > 0$ und $H > 0$ gleich Null sind. Das bedeutet aber, dass bereits die Integranden identisch verschwinden müssen, wodurch sich drei Gleichungen für die Grössen $A_0(\omega)$, $B_0(\omega)$ und $A_1(\omega)$ in den Ansätzen (12) und (15) ergeben. Die Lösungen dieser Gleichungen lauten

$$\left.\begin{aligned} A_0(\omega) &= -\frac{n_2 + i\omega/\delta}{n_2 - n_1}\,\frac{C(\omega)}{F(\omega)}\,\frac{e^{-n_1 \ln \zeta(H)}}{\rho_1 a \omega} \\ B_0(\omega) &= \frac{n_1 + i\,\omega/\delta}{n_2 - n_1}\,\frac{C(\omega)}{F(\omega)}\,\frac{e^{-n_2 \ln \zeta(H)}}{\rho_1 a \omega} \\ A_1(\omega) &= -\frac{C(\omega)}{F(\omega)}\,\frac{e^{i\,\omega H/v_1}}{\rho_1 a \omega} \end{aligned}\right\} \tag{16}$$

mit

$$F(\omega) = \frac{\omega/\delta - i/2}{n_2 - n_1}\left[e^{-n_1 \ln \zeta(H)} - e^{-n_2 \ln \zeta(H)}\right] - \frac{i}{2}\left[e^{-n_1 \ln \zeta(H)} + e^{-n_2 \ln \zeta(H)}\right] \tag{17}$$

Für die uns interessierende Welle $w_1(z, t)$ ergibt sich aus (15), (15a) und (16) der Ausdruck

$$w_1(z, t) = -\frac{1}{\rho_1 a}\int_{-\infty}^{+\infty} \frac{C(\omega)}{F(\omega)}\, e^{i\,\omega\left(t - \frac{z-H}{v_1}\right)}\,\frac{d\omega}{\omega}. \tag{18}$$

Mit Hinblick auf die numerische Auswertung dieses Integrals ist es zweckmässig, die dimensionslosen Grössen

$$2\,\omega/\delta = \sigma \tag{19a}$$

und

$$(\delta/2)\,t = \vartheta \tag{19b}$$

einzuführen. Ausserdem kann man zur Abkürzung

$$\tfrac{1}{2} \ln \zeta(H) = \vartheta_H \tag{20}$$

setzen; dabei ist ϑ_H die dimensionslose Laufzeit einer seismischen Welle in z-Richtung durch die Deckschicht von $z = 0$ bis $z = H$ oder umgekehrt, wie man sich leicht durch direkte Ausrechnung auf Grund des Geschwindigkeitsgesetzes (1a) überzeugt.

Mit den Grössen (19a), (19b) und (20) gehen (14), (17) sowie (11) über in

$$n_{1,2} = -\frac{1}{2}\left[1 \pm i\sqrt{\sigma^2 - 1}\right] \tag{21}$$

$$F(\omega) = G(\sigma) = \frac{\sqrt{\zeta(\overline{H})}}{2} \left[\frac{\sigma - i}{i\sqrt{\sigma^2 - 1}} \left(e^{i\sqrt{\sigma^2-1}\,\vartheta_H} - e^{-i\sqrt{\sigma^2-1}\,\vartheta_H} \right) - i \left(e^{i\sqrt{\sigma^2-1}\,\vartheta_H} + \right.\right.$$
$$\left.\left. + e^{-i\sqrt{\sigma^2-1}\,\vartheta_H} \right) \right] \tag{22}$$

$$C(\omega) = D(\sigma) = \frac{c\,i}{2\,\pi\,\sigma\,\Delta\,\vartheta} \left(e^{-i\,\sigma\,\Delta\,\vartheta} - 1 \right). \tag{23}$$

Der explizite Ausdruck (23) für $D(\sigma)$ wird entsprechend der Bemerkung im Anschluss an (11) vorerst auch weiterhin nicht benötigt.

Hiernach erscheint (18) in der Gestalt

$$w_1(z, \vartheta) = \frac{-1}{\rho_1\,a} \int\limits_{-\infty}^{+\infty} \frac{D(\sigma)}{G(\sigma)}\, e^{i\,\sigma\left[\vartheta - \frac{\delta}{2}\frac{z-H}{v_1}\right]}\, \frac{d\sigma}{\sigma}. \tag{24}$$

Das ist die formale Lösung für die aus der Deckschicht austretende, in der Zwischenschicht nach der positiven z-Richtung fortschreitende Welle.

In (24) ist die Integrationsvariable σ reell. Zur Auswertung des Integrals wird der Satz von Cauchy benutzt; daher setzen wir jetzt σ als komplex voraus und behandeln unser Integrationsproblem in der komplexen σ-Ebene. — Alle bisherigen Integrationen sind entlang der reellen Achse auszuführen. Aus Gründen, die in 4.2 ersichtlich werden, modifizieren wir in (24) den Integrationsweg: Er soll entlang der reellen Achse führen, jedoch nunmehr den Punkt $\sigma = 0$ durch ein kleines Kurvenstück (z.B. einen kleinen Halbkreis) in der unteren Halbebene umgehen[1]. Für sämtliche folgenden, von $-\infty$ nach $+\infty$ erstreckten Integrale gilt dieser modifizierte Integrationsweg.

4.2 *Vorbereitung der Integration.* Mit Hinblick auf die beabsichtigte Verwendung des Satzes von Cauchy zur Berechnung des Integrals (24) werden die folgenden Überlegungen in bezug auf den Integranden angestellt.

Zunächst ist es erforderlich, das Vorzeichen von $\sqrt{\sigma^2 - 1}$ festzulegen. Diese Wurzel verschwindet in den Punkten $\sigma = \pm 1$; das sind die Verzweigungspunkte der zweiblätterigen Riemannschen Fläche für $\sqrt{\sigma^2 - 1}$. Um nun die Wurzel in der komplexen σ-Ebene eindeutig festlegen zu können, wird ein Verzweigungsschnitt gelegt, der die Verzweigungspunkte $\sigma = \pm 1$ längs der reellen Achse miteinander verbindet. Die beiden Blätter der Riemannschen Fläche unterscheiden sich dadurch, dass für $|\sigma| \gg 1$ auf dem einen Blatt $\sqrt{\sigma^2 - 1} \approx \sigma$, auf dem anderen $\sqrt{\sigma^2 - 1} \approx -\sigma$ gilt. Für die weitere Berechnung entscheiden wir uns für das erstere; mit dieser Festsetzung ist nun $\sqrt{\sigma^2 - 1}$ in der ganzen komplexen σ-Ebene umkehrbar eindeutig definiert. Hiernach nimmt die Wurzel entlang der reellen Achse ausserhalb des Verzweigungsschnitts die folgenden Werte an:

---

[1] Diese Abänderung ist zulässig, da auch für den neuen Integrationsweg das Integral (10) die gleiche Funktion $N(t)$ darstellt und ausserdem (12) und (15) Lösungen der Differentialgleichungen bleiben.

$$\sqrt{\sigma^2 - 1} = + \left| \sqrt{\sigma^2 - 1} \right| \text{ für reelle } \sigma > 1 \tag{25a}$$

$$= - \left| \sqrt{\sigma^2 - 1} \right| \text{ für reelle } \sigma < -1. \tag{25b}$$

Wie man leicht zeigt, gilt entlang des Verzweigungsschnitts $-1 < \sigma < 1$ am oberen Ufer desselben

$$\sqrt{\sigma^2 - 1} = + i \left| \sqrt{1 - \sigma^2} \right|, \tag{26a}$$

und am unteren Ufer

$$\sqrt{\sigma^2 - 1} = - i \left| \sqrt{1 - \sigma^2} \right|. \tag{26b}$$

Nunmehr ist eine Untersuchung der Funktion $1/G(\sigma)$ im Integranden von (24) notwendig. Der Ausdruck (22) lässt sich mit Benutzung von (2) und (13) umformen in

$$G(\sigma) = -\frac{i}{2}\sqrt{\frac{v_1}{a}}\left[\left(1 + \frac{\sigma - i}{\sqrt{\sigma^2 - 1}}\right) e^{i\sqrt{\sigma^2-1}\,\vartheta_H} + \left(1 - \frac{\sigma - i}{\sqrt{\sigma^2 - 1}}\right) e^{-i\sqrt{\sigma^2-1}\,\vartheta_H}\right]. \tag{27}$$

Diese Darstellung lässt sofort erkennen, dass $G(\sigma)$ auf der reellen Achse weder ausserhalb des Verzweigungsschnitts noch an den beiden Ufern desselben verschwindet. Daher ist also $1/G(\sigma)$ für reelle σ beschränkt.

Aus (27) folgt

$$\frac{1}{G(\sigma)} = 2i\sqrt{\frac{a}{v_1}}\,\frac{\sqrt{\sigma^2 - 1}\, e^{-i\sqrt{\sigma^2-1}\,\vartheta_H}}{\sqrt{\sigma^2 - 1} + \sigma - i}\left[1 + \frac{\sqrt{\sigma^2 - 1} - \sigma + i}{\sqrt{\sigma^2 - 1} + \sigma - i}\, e^{-2i\sqrt{\sigma^2-1}\,\vartheta_H}\right]^{-1} \tag{28}$$

Die Potenz des Klammerausdrucks soll in eine Reihe entwickelt werden; hierzu bedarf es einer Untersuchung des Faktors

$$Q(\sigma) = \frac{\sqrt{\sigma^2 - 1} - \sigma + i}{\sqrt{\sigma^2 - 1} + \sigma - i}. \tag{29}$$

Auf der reellen Achse ausserhalb des Verzweigungsschnitts, also für $\sigma^2 > 1$, gilt, wenn Q^* zu Q konjugiert ist:

$$Q\,Q^* = \frac{\left(\sqrt{\sigma^2 - 1} - \sigma\right)^2 + 1}{\left(\sqrt{\sigma^2 - 1} + \sigma\right)^2 + 1} = \frac{\sigma^2 - \sigma\sqrt{\sigma^2 - 1}}{\sigma^2 + \sigma\sqrt{\sigma^2 - 1}}. \tag{30}$$

Hieraus folgt mit (25a) und (25b)

$$\left| Q(\sigma) \right| < 1 \text{ für } \sigma^2 > 1, \tag{31}$$

so dass auch

$$\left| Q(\sigma)\, e^{-2i\sqrt{\sigma^2-1}\,\vartheta_H} \right| < 1 \text{ für } \sigma^2 > 1. \tag{32}$$

Am oberen bzw. unteren Ufer des Verzweigungsschnitts gilt das obere bzw. untere Vorzeichen in

$$Q(\sigma) = \frac{-\sigma + i\,(1 \pm |\sqrt{1-\sigma^2}|)}{\sigma - i\,(1 \mp |\sqrt{1-\sigma^2}|)} \quad \text{für } \sigma^2 < 1, \tag{33}$$

entsprechend auch in

$$Q\,Q^* = \frac{\sigma^2 + (1 \pm |\sqrt{1-\sigma^2}|)^2}{\sigma^2 + (1 \mp |\sqrt{1-\sigma^2}|)^2}. \tag{34}$$

Somit ist am oberen Ufer $|Q(\sigma)| > 1$, am unteren Ufer jedoch $|Q(\sigma)| < 1$. Für beide Ufer wird ausserdem die Exponentialfunktion in der eckigen Klammer von (28) rein reell, und zwar grösser als 1 am oberen, kleiner als 1 am unteren Ufer. Hiernach gilt die Ungleichung

$$|Q(\sigma)\, e^{-2i\sqrt{\sigma^2-1}\,\vartheta_H}| < 1 \quad \text{für } \sigma^2 < 1 \tag{35}$$

am unteren Ufer unseres Verzweigungsschnitts.

Nunmehr zurück zum Integral (24). Auf Grund der Festlegung des Integrationsweges am Schluss von 4.1 führt dieser entlang der reellen Achse und umgeht den Verzweigungsschnitt an seinem unteren Ufer. Für alle Punkte des Weges lässt sich vermöge (32) und (35) anstelle von (28) die Reihe

$$\frac{1}{G(\sigma)} = 2i\sqrt{\frac{a}{v_1}}\,\frac{\sqrt{\sigma^2-1}\; e^{-i\sqrt{\sigma^2-1}\,\vartheta_H}}{\sqrt{\sigma^2-1} + \sigma - i}\sum_{\nu=0}^{\infty}(-1)^\nu\, Q^\nu(\sigma)\, e^{-2i\nu\sqrt{\sigma^2-1}\,\vartheta_H}, \tag{36}$$

verwenden, die absolut und gleichmässig konvergiert.

Mit der Umformung

$$\frac{1}{\sqrt{\sigma^2-1} + \sigma - i} = \frac{1}{2\sigma}\,\frac{\sqrt{\sigma^2-1} + \sigma + i}{\sqrt{\sigma^2-1} + \sigma} = \frac{1}{2\sigma}\left[1 + i\,(\sigma - \sqrt{\sigma^2-1})\right] \tag{37}$$

liefert die Einführung von (36) in das Integral (24) den Ausdruck

$$w_1(z,\vartheta) = \frac{-i}{\rho_1\sqrt{a\,v_1}}\sum_{\nu=0}^{\infty}(-1)^\nu\int_{-\infty}^{+\infty}\left[1 + i\,(\sigma - \sqrt{\sigma^2-1})\right]\sqrt{\sigma^2-1}\,D(\sigma)\,Q^\nu(\sigma)\; e^{i\{\sigma\theta - (2\nu+1)\sqrt{\sigma^2-1}\,\vartheta_H\}}\,\frac{d\sigma}{\sigma^2} \tag{38}$$

mit

$$\theta = \vartheta - \frac{\delta}{2}\,\frac{z-H}{v_1}. \tag{39}$$

Die einzelnen Summanden in (38) haben die folgende physikalische Bedeutung: Der Summand für $\nu = 0$ stellt die direkt gebrochene Welle dar, die also nur einmal durch die Deckschicht gelaufen ist. Der Summand für $\nu = 1$ ist die Welle, die nach Reflexion an $z = H$ und Reflexion an $z = 0$ in die Zwischenschicht eingetreten ist. Allgemein bedeutet der ν^{te} Summand, der mit $w_{1,\nu}$ bezeichnet werden möge, diejenige Welle, die nach ν-facher Reflexion an $z = H$ und ν-facher Reflexion an $z = 0$ in die Zwischenschicht hineingebrochen worden ist.

Die von diesen einzelnen Teilwellen an einem festen Ort z der Zwischenschicht verursachten elastischen Bewegungen laufen zeitlich in folgender Weise ab:

$$\left.\begin{aligned} & w_{1,\nu}(z,\vartheta) = 0 \quad \text{für } \vartheta < \frac{\delta}{2}\,\frac{z-H}{v_1} + (2\nu+1)\,\vartheta_H, \\ & w_{1,\nu}(z,\vartheta) = \frac{-i\,(-1)^\nu}{\rho_1\sqrt{a\,v_1}} \int\limits_{-\infty}^{+\infty} [1 + i\,(\sigma - \sqrt{\sigma^2-1})]\,\sqrt{\sigma^2-1}\;D(\sigma)\,Q^\nu(\sigma) \\ & \qquad\qquad e^{i\{\sigma\,\theta-(2\nu+1)\sqrt{\sigma^2-1}\,\vartheta_H\}}\,\frac{d\sigma}{\sigma^2} \\ & \qquad \text{für } \vartheta > \frac{\delta}{2}\,\frac{z-H}{v_1} + (2\nu+1)\,\vartheta_H\,, \\ & \qquad \nu = 0, 1, 2, 3, \ldots \end{aligned}\right\} \qquad (40)$$

Die elastische Störung beginnt ja nach (3) und (19b) bei $z = 0$ zur Zeit $\vartheta = 0$; sie benötigt zum einmaligen Lauf durch die Deckschicht die Zeit ϑ_H und für den Weg in der Zwischenschicht von $z = H$ bis z die Zeit $(\delta/2)\,(z-H)/v_1$.

Nach diesen Vorbereitungen wird im nächsten Abschnitt die Auswertung des Integrals (40) skizziert und für den Fall $\nu = 0$ explizit durchgeführt.

4.3 *Durchführung der Integration.* Wir denken uns in (40) für $D(\sigma)$ den Ausdruck (23) eingesetzt; hierdurch wird $w_{1,\nu}$ auch eine Funktion der Dauer $\triangle\vartheta = (\delta/2)\triangle t$ des Normaldruckes $N(t)$ aus (3). Diese Abhängigkeit verschwindet mit dem bereits im Anschluss an (3) angekündigten Grenzübergang $\triangle\vartheta \to 0$. Vertauscht man den Grenzprozess mit dem Integrationsprozess (40), so ergibt sich nach Ausführung des ersteren

$$\left.\begin{aligned} & w_{1,\nu}(z,\vartheta) = \frac{-i\,(-1)^\nu}{\rho_1\sqrt{a\,v_1}}\,\frac{c}{2\pi} \int\limits_{-\infty}^{+\infty} [1 + i\,(\sigma - \sqrt{\sigma^2-1})]\,\sqrt{\sigma^2-1}\;Q^\nu(\sigma) \\ & \qquad\qquad e^{i\{\sigma\,\theta-(2\nu+1)\sqrt{\sigma^2-1}\,\vartheta_H\}}\,\frac{d\sigma}{\sigma^2} \\ & \qquad \text{für } \theta > (2\nu+1)\,\vartheta_H;\ \nu = 0, 1, 2, 3, \ldots \end{aligned}\right\} \qquad (41)$$

Der Integrand hat ausser in $\sigma = 0$ keine Pole, wie aus (29) und (37) sofort zu ersehen ist.

Zur Auswertung von (41) kann man sich des Satzes von Cauchy bedienen.

Das Integral ist dabei in der komplexen σ-Ebene über eine geschlossene Kurve zu nehmen, die den Verzweigungsschnitt umschliesst. Mit der Grösse

$$\tau_\nu = \frac{(2\nu + 1)\,\vartheta_H}{\theta} \tag{42}$$

für die nach (40)

$$0 < \tau_\nu < 1 \tag{43}$$

gilt, sowie der Grösse

$$\eta_\nu = {}_{(+)}\sqrt{\frac{1-\tau_\nu}{1+\tau_\nu}} \tag{44}$$

erfolgt die Festlegung der geschlossenen Kurve K_ν für das Integral $w_{1,\nu}$ durch

$$\sigma_\nu(\varphi) = \frac{1}{{}_{(+)}\sqrt{1-\tau_\nu^2}}\{\cos\varphi + i\,\tau_\nu\sin\varphi\} = \frac{1}{2\,\eta_\nu}\{e^{i\varphi} + \eta_\nu^2\,e^{-i\varphi}\};\ 0 \leqq \varphi \leqq 2\pi \tag{45}$$

Auf der Kurve K_ν werden

$$d\sigma_\nu = \frac{i}{{}_{(+)}\sqrt{1-\tau_\nu^2}}\{\tau_\nu\cos\varphi + i\sin\varphi\}\,d\varphi = \frac{i}{2\,\eta_\nu}\{e^{i\varphi} - \eta_\nu^2\,e^{-i\varphi}\} \tag{46}$$

und wegen (25a, b)

$$\sqrt{\sigma_\nu^2 - 1} = \frac{1}{{}_{(+)}\sqrt{1-\tau_\nu^2}}\{\tau_\nu\cos\varphi + i\sin\varphi\} = \frac{1}{2\,\eta_\nu}\{e^{i\varphi} - \eta_\nu^2\,e^{-i\varphi}\}. \tag{47}$$

Die Anwendung des Satzes von Cauchy auf (41) ergibt

$$w_{1,\nu}(z,\vartheta) = \frac{-i\,(-1)^\nu}{\rho_1\sqrt{a}\,v_1}\,\frac{c}{2\pi}\oint\limits_{K_\nu}[1 + i\,(\sigma - \sqrt{\sigma^2-1})]\sqrt{\sigma^2-1}\;Q^\nu(\sigma)\,\frac{1}{\sigma^2}\,\frac{d\sigma}{d\varphi}\; e^{i\,\theta\,\{\sigma-\tau_\nu\sqrt{\sigma^2-1}\}}\,d\varphi \tag{48}$$

für $\theta > (2\,\nu + 1)\,\vartheta_H$; $\nu = 1, 0, 2, 3, \ldots$

Trägt man in den Integranden die Ausdrücke (45)-(47) ein, so wird wegen (29) das gesamte Produkt vor der Exponentialfunktion eine gebrochen rationale Funktion von $\cos\varphi$ und $\sin\varphi$ bzw. von $e^{i\varphi}$ und $e^{-i\varphi}$. Diese gebrochen rationale Funktion kann durch eine Fourier-Reihe dargestellt werden:

$$[1 + i\,(\sigma_\nu - \sqrt{\sigma_\nu^2-1})]\sqrt{\sigma_\nu^2-1}\;Q^\nu(\sigma_\nu)\,\frac{1}{\sigma_\nu^2}\,\frac{d\sigma_\nu}{d\,\varphi} = \sum_{\mu=-\infty}^{+\infty}\alpha_{\mu,\nu}\,e^{i\,\mu\,\varphi}. \tag{49}$$

Nach Einsetzen von (49) in (48) und Vertauschung der Reihenfolge von Integration und Summation folgt

$$w_{1,\nu}(z,\vartheta) = \frac{-i\,(-1)^\nu}{\rho_1\sqrt{a}\,v_1}\,\frac{c}{2\pi}\sum_{\mu=-\infty}^{+\infty}\alpha_{\mu,\nu}\int_0^{2\pi} e^{i\,\theta\sqrt{1-\tau_\nu^2}\,\cos\varphi}\;e^{i\,\mu\,\varphi}\,d\,\varphi. \tag{50}$$

Mit Benutzung der bekannten Integraldarstellung

$$I_\mu(x) = \frac{i^{-\mu}}{2\pi} \int_0^{2\pi} e^{i\,x\cos\varphi}\, e^{i\,\mu\,\varphi}\, d\varphi \tag{51}$$

der Besselschen Funktion der Ordnung μ geht (50) über in

$$\left.\begin{array}{l} w_{1,\nu}(z,\vartheta) = \dfrac{-i(-1)^\nu c}{\rho_1 \sqrt{a\,v_1}} \displaystyle\sum_{\mu=-\infty}^{+\infty} i^\mu\, \alpha_{\mu,\nu}\, I_\mu\left(\theta\sqrt{1-\tau_\nu^2}\right) \\ \text{für } \theta > (2\nu+1)\,\vartheta_H;\ \nu = 0, 1, 2, 3, \ldots \end{array}\right\}, \tag{52}$$

was wegen (42) gleichbedeutend ist mit

$$\left.\begin{array}{l} w_{1,\nu}(z,\vartheta) = \dfrac{-i(-1)^\nu c}{\rho_1 \sqrt{a\,v_1}} \displaystyle\sum_{\mu=-\infty}^{+\infty} i^\mu\, \alpha_{\mu,\nu}\, I_\mu\left(\sqrt{\theta^2-[(2\nu+1)\vartheta_H]^2}\right) \\ \qquad\text{für } \theta > (2\nu+1)\,\vartheta_H;\ \nu = 0, 1, 2, 3, \ldots \end{array}\right\}. \tag{52a}$$

Das ist die allgemeine Formel zur Berechnung von $w_{1,\nu}$, in die neben den tabellarisch zugänglichen Besselschen Funktionen I_μ die Fourier-Koeffizienten $\alpha_{\mu,\nu}$ von (49) eingehen.

Um den Ablauf der elastischen Bewegung näher studieren zu können, wird der Fall $\nu = 0$, also die direkt gebrochene Welle explizit berechnet. Es ist zweckmässig, anstelle der Verschiebung $w_{1,0}$ die Beschleunigung $\partial^2 w_{1,0}/\partial\,\vartheta^2$ zu berechnen, da dann die (49) entsprechende Fourier-Reihe nur endlich viele Summanden hat. Differenzieren wir nämlich (48) für $\nu = 0$ mit Beachtung von (39) zweimal nach ϑ, was unter dem Integralzeichen geschehen darf, so ergibt sich

$$\frac{\partial^2 w_{1,0}}{\partial\,\vartheta^2} = \frac{i}{\rho_1\sqrt{a\,v_1}}\,\frac{c}{2\pi} \oint_{K_0} \left[1 + i\left(\sigma - \sqrt{\sigma^2-1}\right)\right] \sqrt{\sigma^2-1}\,\frac{d\sigma}{d\varphi}\, e^{i\,\theta\,\{\sigma-\tau_0\sqrt{\sigma^2-1}\}}\, d\varphi; \qquad \theta > \vartheta_H. \tag{53}$$

Führt man in den Integranden die Exponentialausdrücke von (45), (46), (47) für $\nu = 0$ ein, so folgt

$$\begin{aligned} \frac{\partial^2 w_{1,0}}{\partial\,\vartheta^2} = \frac{1}{\rho_1\sqrt{a\,v_1}}\,\frac{c}{2\pi}\,\frac{1}{4\eta_0^2} \int_0^{2\pi} e^{i\,\theta\sqrt{1-\tau_0^2}\cos\varphi} \Big[& 2\eta_0^2 + \eta_0\, i^{-1} e^{i\varphi} + 2\eta_0^3\, i\, e^{-i\varphi} + \\ & + i^{-2} e^{2i\varphi} + \eta_0^4\, i^2 e^{-2i\varphi} + \eta_0^5\, i^3 e^{-3i\varphi} \Big]\, d\varphi \end{aligned} \tag{54}$$

Hieraus lässt sich mit Verwendung von (51) und der bekannten Funktionalgleichung

$$J_{-\mu}(x) = (-1)^\mu\, I_\mu(x) \tag{55}$$

sowie mit (42) leicht der nachstehende Ausdruck gewinnen:

$$\frac{\partial^2 w_{1,0}}{\partial \vartheta^2} = \frac{c}{4\,\rho_1 \sqrt{a\,v_1}\,\eta_0^2} \Big\{ 2\,\eta_0^2\, I_0\left(\sqrt{\theta^2-\vartheta_H^2}\right) + \eta_0\,(1-2\eta_0^2)\, I_1\left(\sqrt{\theta^2-\vartheta_H^2}\right)$$
$$+ (1+\eta_0^4)\, I_2\left(\sqrt{\theta^2-\vartheta_H^2}\right) - \eta_0^5\, I_3\left(\sqrt{\theta^2-\vartheta_H^2}\right) \Big\}; \quad \theta > \vartheta_H \qquad (56)$$

Diese Formel ist der Ausgangspunkt für die numerischen Rechnungen, deren Ergebnisse im nächsten Abschnitt mitgeteilt werden.

4.4 *Numerische Ergebnisse.* Um einen Eindruck vom Ablauf der Wellenbewegung zu erhalten, haben wir in drei Fällen die Geschwindigkeit $\partial w_{1,0}/\partial \vartheta$ berechnet, die am Ort z der Zwischenschicht von einem gebräuchlichen Feldseismographen registriert werden würde. Hierzu wurde (56) für vorgegebenes ϑ_H berechnet und als Funktion von

$$\vartheta^* = \theta - \vartheta_H = \vartheta - \frac{\delta}{2}\,\frac{z-H}{v_1} - \vartheta_H\,, \qquad (57)$$

also der Zeit nach Eintreffen der Welle am Ort z, graphisch dargestellt; ein Integriergerät lieferte dann die Geschwindigkeit.

Fig. 3 veranschaulicht in willkürlichen Einheiten die Geschwindigkeit der Bodenbewegung in der Zwischenschicht für $\vartheta_H = 0.80$. Fig. 4 zeigt im Vergleich hierzu mit den entsprechenden Kurven für $\vartheta_H = 0.02$ und $\vartheta_H = 1.15$ den Einfluss der Mächtigkeit der Deckschicht auf die Gestalt der Welle in der Zwischenschicht.

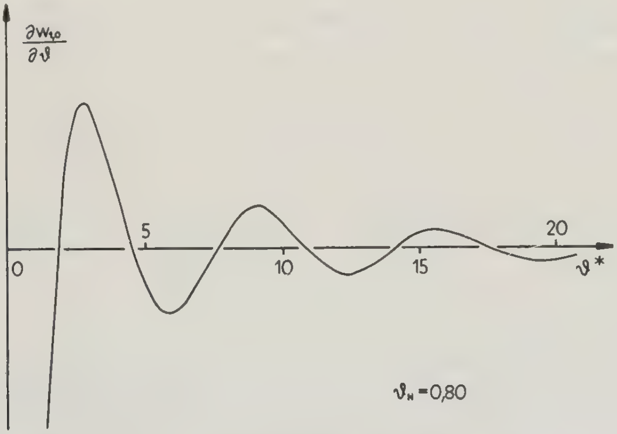


Fig. 3. Geschwindigkeit der Bodenbewegung an einem beliebigen Ort z der Zwischenschicht bei Durchgang der Welle $w_{1,0}$. Laufzeit der Welle durch die Deckschicht $\vartheta_H = 0{,}80$.
Velocity of a particle at an arbitrary point z of the intermediate layer during the passage of the wave $w_{1,0}$. Travel time of the wave through the uppermost layer $\vartheta_H = 0{,}80$.

Die Funktionen sind in $\vartheta^* = 0$ nicht stetig, was in Anbetracht der gewählten Erregung der elastischen Wellen nicht verwunderlich ist. Jedoch darf die quasi-periodische Natur der Bilder als bedeutungsvoll angesehen werden, denn der elastische Vorgang ist durch eine absolut unperiodische Störung hervorgerufen worden. Es ist die ,,Frequenz'' nahezu konstant während des Bewegungsablaufs, was erheblich von den Verhältnissen bei der Fortpflanzung seismischer Wellen in nicht-ideal elastischen Medien abweicht. Die Mächtigkeit der Deckschicht hat keinen Einfluss auf den Typus der Bewegung, sondern nur auf die Amplitude und ,,Phase'' derselben. — Hiermit werde die Diskussion der numerischen Ergebnisse vorerst beendet. Sie wird in Abschnitt 6 (Schlussbemerkung) nochmals aufgenommen und weitergeführt, insbesondere hinsichtlich des Zusammenhangs zwischen der ,,Frequenz'' der Bodenschwingungen und dem Gradienten der Fortpflanzungsgeschwindigkeit v_0 in der Deckschicht.

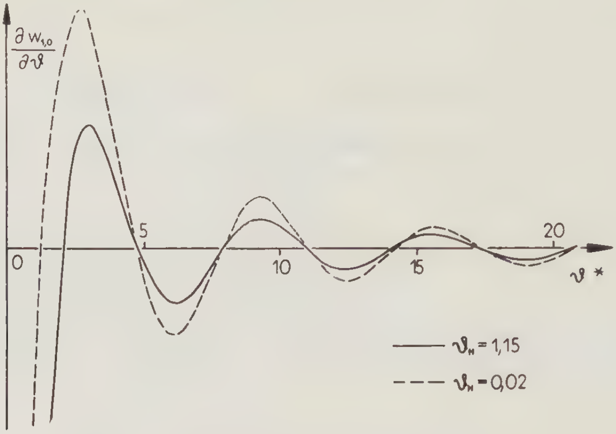


Fig. 4. Geschwindigkeit der Bodenbewegung an einem beliebigen Ort z der Zwischenschicht für zwei Wellen $w_{1,0}$. Laufzeiten der Wellen durch die Deckschicht $\vartheta_H = 0{,}02$ bzw. $\vartheta_H = 1{,}15$.

Velocity of a particle at an arbitrary point z of the intermediate layer during the passage of two waves of type $w_{1,0}$. Travel times of the waves through the uppermost layer $\vartheta_H = 0{,}02$ resp. $1{,}15$.

Die explizite Berechnung weiterer Teilwellen $w_{1,\nu}$ ist auf Grund der bisherigen Ausführungen ohne Schwierigkeiten zu erledigen. Wir haben von einer solchen Abstand genommen, da wir nur den Typus der elastischen Bewegung studieren wollen, die von der angenommenen Störung verursacht wird. — Daher wenden wir uns nunmehr unserem zweiten, eingangs formulierten Problem zu, nämlich der Berechnung derjenigen Welle, die nach einmaliger Reflexion am Horizont $z = T$ an der Erdoberfläche $z = O$ beobachtet werden kann.

5. Die Welle an der Erdoberfläche $z = O$ nach einmaliger Reflexion am Horizont $z = T$

Mit Hinblick auf die Verhältnisse in der Praxis machen wir die folgende Voraussetzung: Die (dimensionslose) Laufzeit $\delta\,(T\text{-}H)/2\,v_1$ der Kompressionswelle durch die gesamte Zwischenschicht sei hinreichend gross gegenüber der Laufzeit ϑ_H aus (20) durch die Deckschicht. Hinreichend bedeutet hierbei, dass die Bewegung in der Deckschicht bereits praktisch abgeklungen ist, wenn die Welle w_1 von (38) nach Reflexion am Horizont $z = T$ wiederum die Deckschicht erreicht. Denn auf Grund der Erläuterung im Anschluss an (39) haben bis zu diesem Zeitpunkt in der Deckschicht viele Reflexionen an $z = H$ und $z = O$ stattgefunden, wobei jede Reflexion an $z = H$ mit einer Abgabe von Bewegungsenergie an die Zwischenschicht verbunden ist. — Für unser Ziel der Berechnung der Welle an der Erdoberfläche $z = O$ idealisieren wir den soeben gekennzeichneten Sachverhalt dahingehend, dass die Deckschicht sich in vollkommener Ruhe befinden soll, wenn sie von der am Horizont $z = T$ reflektierten Welle erreicht wird. Hierdurch lässt sich die mathematische Behandlung in der nachstehend skizzierten Weise durchführen, wobei sukzessive die Randbedingungen an $z = T$ einerseits sowie an $z = H$ und $z = O$ andererseits berücksichtigt werden [1]).

5.1 *Skizzierung der Berechnung.* Wir gehen aus von Formel (18) und betrachten w_1 als einfallende Welle, die am Horizont $z = T$ in den reflektierten Anteil $\overline{w}_1$ und den gebrochenen Anteil w_2 aufgespalten wird. Der Lösungsansatz für die Zwischenschicht lautet

$$W_1(z, t) = \int_{-\infty}^{+\infty} [A_1(\omega)\, e^{i\omega\,(t-z/v_1)} + \beta_1(\omega)\, e^{i\omega\,(t+z/v_1)}]\, d\omega \tag{58}$$

mit $A_1(\omega)$ aus (16), so dass für (58) auch abkürzend

$$W_1(z, t) = w_1(z, t) + \overline{w}_1(z, t) \tag{58a}$$

geschrieben werden kann. Im Halbraum ist anzusetzen:

$$w_2(z, t) = \int_{-\infty}^{+\infty} A_2(\omega)\, e^{i\omega\,(t-z/v_2)}\, d\omega. \tag{59}$$

---

[1]) Ohne unsere idealisierende Voraussetzung müssten entgegen dem in 5.1 geschilderten Verfahren die Randbedingungen (7), (8), (9) simultan berücksichtigt werden. Die so erhaltene allgemeine Lösung für w_0 enthielte sämtliche Wellenanteile in der Deckschicht, d.h. sowohl diejenigen, die durch Reflexionen an $z = H$ und $z = O$ innerhalb der Deckschicht laufen, als auch diejenigen, die nach Mehrfachreflexionen an den Horizonten $z = T$ und $z = H$ aus der Zwischenschicht wieder in die Deckschicht eintreten. Aus dieser allgemeinen Lösung müsste dann die uns interessierende Welle erst ausgesondert werden.

Gemäss (9) müssen die Funktionen W_1 und w_2 den Randbedingungen

$$W_1 = w_2 \text{ und } \rho_1 v_1^2 \frac{\partial W_1}{\partial z} = \rho_2 v_2^2 \frac{\partial w_2}{\partial z} \qquad \text{für } z = T \tag{60}$$

genügen. Hieraus errechnet sich

$$\beta_1(\omega) = R\, e^{-2 i \omega T/v_1} A_1(\omega), \tag{61}$$

wobei

$$R = \frac{\rho_1 v_1 - \rho_2 v_2}{\rho_1 v_1 + \rho_2 v_2} \tag{62}$$

der bekannte Reflexionskoeffizient ist. Damit wird

$$\overline{w}_1(z, t) = -\frac{R}{\rho_1 a} \int_{-\infty}^{+\infty} \frac{C(\omega)}{F(\omega)} e^{i \omega (t - \frac{2T-H-z}{v_1})} \frac{d\omega}{\omega}. \tag{63}$$

Diese Welle läuft in der Zwischenschicht nach oben und trifft bei $z = H$ auf die Deckschicht, die sich nach unserer idealisierenden Voraussetzung in vollkommener Ruhe befindet. Die Welle wird an $z = H$ reflektiert und gebrochen. Der gebrochene Anteil erreicht die Erdoberfläche $z = O$ und wird dort reflektiert, usw. Uns interessiert nun der Bewegungsablauf an der Erdoberfläche $z = O$.

Als Lösung in der Zwischenschicht setzen wir an

$$\overline{W}_1(z, t) = \int_{-\infty}^{+\infty} [\overline{A}_1(\omega)\, e^{i\omega(t - z/v_1)} + \beta_1(\omega)\, e^{i\omega(t + z/v_1)}]\, d\omega \tag{64}$$

mit $\beta_1(\omega)$ aus (61); der zweite Summand von (64) bedeutet also die einfallende, der erste die reflektierte Welle. Entsprechend (12) ist in der Deckschicht anzusetzen:

$$\overline{w}_0(z, t) = \int_{-\infty}^{+\infty} [\overline{A}_0(\omega)\, e^{n_1 ln \zeta} + \overline{B}_0(\omega)\, e^{n_2 ln \zeta}]\, e^{i\omega t}\, d\omega, \tag{65}$$

wobei ζ und $n_{1,2}$ durch (13) und (14) gegeben sind. Die Funktionen $\overline{W}_1$ und $\overline{w}_0$ müssen entsprechend (7), (8) den Randbedingungen

$$\frac{\partial \overline{w}_0}{\partial z} = o \qquad \text{für } z = O \tag{66}$$

$$\overline{w}_0 = \overline{W}_1 \text{ und } \frac{\partial \overline{w}_0}{\partial z} = \frac{\partial \overline{W}_1}{\partial z} \qquad \text{für } z = H \tag{67}$$

genügen.

Wir suchen $\overline{w}_0(O, t)$, das wegen (65) und (13) durch den Ausdruck

$$\overline{w}_0\,(O,t) = \int\limits_{-\infty}^{+\infty} [\overline{A}_0\,(\omega) + \overline{B}_0\,(\omega)]\; e^{i\,\omega\,t}\,d\,\omega \tag{68}$$

dargestellt wird.

Aus den Randbedingungen (66), (67) errechnet man leicht

$$\overline{A}_0\,(\omega) = \frac{-2\,i\,\omega\,n_2\,e^{i\,\omega\,H/v_1}}{n_1\,(i\,\omega + \delta\,n_2)\,e^{n_2\,ln\,\zeta\,(H)} - n_2\,(i\,\omega + \delta\,n_1)\,e^{n_1\,ln\,\zeta\,(H)}}\,\beta_1\,(\omega), \tag{69}$$

$$\overline{B}_0(\omega) = \frac{2\,i\,\omega\,n_1\;e^{i\,\omega\,H/v_1}}{n_1\,(i\,\omega + \delta\,n_2)\,e^{n_2\,ln\,\zeta\,(H)} - n_2\,(i\,\omega + \delta\,n_1)\,e^{n_1\,ln\,\zeta\,(H)}}\,\beta_1\,(\omega) \tag{70}$$

mit $\beta_1\,(\omega)$ aus (61).

Bei Benutzung der dimensionslosen Grössen σ, ϑ und ϑ_H von (19a), (19b) und (20) folgt nach einigen Umformungen, die denjenigen im Anschluss an (21) entsprechen, aus (69) und (70)

$$\overline{A_0} + \overline{B_0} = \frac{4\,\sqrt{v_1/a}\,\sqrt{\sigma^2 - 1}}{\sqrt{\sigma^2 - 1} + \sigma - i}\;e^{i\,\sigma\,\frac{\delta}{2}\,\frac{H}{v_1}} \left\{\sum_{\varkappa=0}^{\infty} (-1)^{\varkappa}\,Q^{\varkappa}\,(\sigma)\;e^{-i\,(2\varkappa+1)\,\sqrt{\sigma^2 - 1}\,\vartheta_H}\right\}\beta_1, \tag{71}$$

wo $Q\,(\sigma)$ durch (29) gegeben ist. Für β_1 als Funktion von σ ergibt sich wegen (22), (23) und (36) der Ausdruck

$$\beta_1 = \frac{-\,2\,i\,R\,\sqrt{a/v_1}\,D\,(\sigma)}{\rho_1\,a\,(\delta/2)\,\sigma}\;\frac{\sqrt{\sigma^2 - 1}\;e^{-i\,\sigma\,\frac{\delta}{2}\,\frac{2\,T - H}{v_1}}}{\sqrt{\sigma^2 - 1} + \sigma - i}\sum_{\nu=0}^{\infty} (-1)^{\nu}\,Q^{\nu}\,(\sigma)\;e^{-i\,(2\nu+1)\,\sqrt{\sigma^2 - 1}\,\vartheta_H} \tag{72}$$

mit dem gleichen $Q\,(\sigma)$ wie in (71).

Führt man nunmehr (71) und (72) in (68) ein, geht wie bei (41) mit $\triangle\,\vartheta$ gegen Null und benutzt ausserdem noch die Beziehung (37), so folgt

$$\overline{w}_0\,(O,\vartheta) = \frac{-2\,Rc}{\rho_1\,a\,\pi}\sum_{\nu=0}^{\infty}\sum_{\varkappa=0}^{\infty}(-1)^{\nu+\varkappa}\int\limits_{-\infty}^{+\infty}(\sigma^2 - 1)\,Q^{\nu+\varkappa+1}(\sigma)\;e^{i\{\sigma\,\overline{\theta} - 2(\nu+\varkappa+1)\sqrt{\sigma^2 - 1}\,\vartheta_H\}}\,\frac{d\sigma}{\sigma^2} \tag{73}$$

mit

$$\overline{\theta} = \vartheta - \delta\,\frac{T - H}{v_1}. \tag{74}$$

Formel (73) für die nach einmaliger Reflexion am Horizont $z = T$ an der Erdoberfläche $z = O$ zu beobachtende Welle ist offenbar das Analogon zu Formel (38) für die Welle w_1. Die Deutung von (73) sowie ein numerisches Beispiel werden im nächsten Abschnitt gegeben.

5.2 *Deutung des Ergebnisses und ein numerisches Beispiel.* Wir schreiben für (73) abkürzend

$$\overline{w}_0\,(O,\,\vartheta) = \sum_{\nu=0}^{\infty}\sum_{\varkappa=0}^{\infty}\overline{w}_{0,\,\nu,\,\varkappa}\,(O,\,\vartheta), \tag{75}$$

wobei die einzelnen Summanden Teilwellen bedeuten. Da die elastische Störung nach (3) und (19b) bei $z = O$ zur Zeit $\vartheta = o$ beginnt, laufen die elastischen Bewegungen, die von den Teilwellen (75) verursacht werden, zeitlich in folgender Weise ab:

$$\overline{w}_{0,\,\nu,\,\varkappa}\,(O,\,\vartheta) = o \quad \text{für} \quad \vartheta < \delta\,\frac{T-H}{v_1} + 2\,(\nu+\varkappa+1)\,\vartheta_H,$$

$$\overline{w}_{0,\,\nu,\,\varkappa}(O,\vartheta) = \frac{-2\,Rc(-1)^{\nu+\varkappa}}{\rho_1\,a\,\pi}\int_{-\infty}^{+\infty}(\sigma^2-1)\,Q^{\nu+\varkappa+1}(\sigma)\,e^{i\,\{\sigma\,\overline{\theta}-2\,(\nu+\varkappa+1)\sqrt{\sigma^2-1}\,\vartheta_H\}}\,\frac{d\sigma}{\sigma^2} \tag{76}$$

$$\text{für } \vartheta > \delta\,\frac{T-H}{v_1} + 2\,(\nu+\varkappa+1)\,\vartheta_H,$$

$$\nu = 0,\,1,\,2,\,3,\,\ldots$$

$$\varkappa = 0,\,1,\,2,\,3,\,\ldots$$

Mit Hinblick auf (71) und (72) sowie die Erläuterung im Anschluss an (39) haben die Indizes ν, $\varkappa$ die folgende Bedeutung: Der Index ν gibt an, wie oft die Teilwelle an $z = H$ und $z = O$ reflektiert wurde, bevor sie in die Zwischenschicht eingetreten ist, um sodann dort am Horizont $z = T$ reflektiert zu werden. Der Index $\varkappa$ gibt an, wie oft die Teilwelle nach Reflexion am Horizont $z = T$ und Eintritt in die Deckschicht an $z = O$ und $z = H$ reflektiert wurde. Naturgemäss gilt

$$\overline{w}_{0,\,\nu,\,\varkappa}\,(O,\,\vartheta) = \overline{w}_{0,\,\varkappa,\,\nu}\,(O,\,\vartheta). \tag{77}$$

Die Auswertung der Integrale (76) geschieht nach der in Abschnitt 4.3 geschilderten Methode. Prinzipielle Schwierigkeiten treten dabei nicht auf; man wird wiederum auf Besselfunktionen geführt.

Als numerisches Beispiel veranschaulicht Fig. 5 in willkürlichen Einheiten die Geschwindigkeit $\partial\, w_0/\partial\,\vartheta$ bei vorgegebenem ϑ_H als Funktion von

$$\overline{\vartheta}^* = \overline{\theta} - 2\,\vartheta_H = \vartheta - \delta\,\frac{T-H}{v_1} - 2\,\vartheta_H; \tag{78}$$

d.h. als Funktion der Zeit nach Eintreffen der Teilwelle $w_{0,\,0,\,0}$. Es sind hierbei in (75) die ersten drei Summanden berücksichtigt worden, d.h. für $\nu = \varkappa = 0$; $\nu = 0$, $\varkappa = 1$ und $\nu = 1$, $\varkappa = 0$; die weiteren Summanden spielen praktisch keine Rolle mehr.

Das Schwingungsbild der Fig. 5 ist sehr ähnlich demjenigen in Fig. 3. Die geringen Unterschiede in den Abständen der Nullstellen in den beiden Bildern können wohl z.T. darauf zurückgeführt werden, dass in Fig. 3 nur $w_{1,0}$ und nicht auch noch $w_{1,1}$ wiedergegeben ist, was notwendig wäre, wenn man einen quantitativen Vergleich durchführen wollte. Ausserdem dürfte die Genauigkeit der numerischen Rechnung für quantitative Aussagen nicht ganz ausreichend sein, was jedoch bei der Durchführung derselben gar nicht angestrebt wurde.

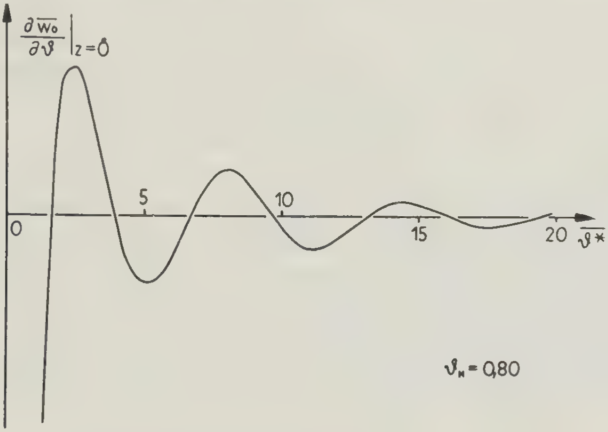


Fig. 5. Geschwindigkeit der Bodenbewegung an der Erdoberfläche $z = O$ für die Welle $\overline{w}_0$, die am Horizont $z = T$ der Fig. 1 einmal reflektiert worden ist. Laufzeit der Welle durch die Deckschicht $\vartheta_H = 0{,}80$.

Velocity of a particle at the earth's surface $z = O$ for the wave $\overline{w}_0$ being reflected once at the horizon $z = T$ of fig. 1. Travel time of the wave through the uppermost layer $\vartheta_H = 0{,}80$.

6. SCHLUSSBEMERKUNG

Wie bereits in Abschnitt 4.4. zum Ausdruck gebracht wurde, darf die quasiperiodische Natur der errechneten Schwingungsbilder als bedeutungsvoll angesehen werden. Ersichtlich besitzen die Schwingungen eine Pseudo-Periode im dimensionslosen Zeitmass ϑ von ungefähr 2π, da ja die Nullstellen der Bessel-Funktionen näherungsweise einen solchen Abstand voneinander haben. Hieraus errechnet sich vermöge (19b) die Pseudo-Frequenz der Welle zu

$$f \approx \frac{\delta}{4\pi}. \tag{79}$$

Die Pseudo-Frequenz ist also vom Gradienten δ der Geschwindigkeit v_0 aus (1a) abhängig, was nach den Ausführungen in der Einleitung durchaus plausibel ist.

Setzen wir nun mit Hinblick auf die Beobachtungen in der Praxis für f den Wert 50 Hz ein, so ergibt sich

$$\delta \approx 628 \frac{m/\text{sec}}{m} . \tag{80}$$

Der Wert (80) des Gradienten der Geschwindigkeit ist bedeutend grösser als man ihn im Normalfall erwarten kann. Diese Diskrepanz zwischen Theorie und Praxis kann z.T. dadurch bedingt sein, dass die eingangs angegebenen Voraussetzungen zu stark vereinfacht sind. Inwieweit die Voraussetzungen abzuändern wären, müssten erst direkte Messungen des Geschwindigkeitsanstiegs in der Verwitterungsschicht sowie der Gestalt sprengseismischer Impulse zeigen.

Auf jeden Fall kann man wohl mit Hinblick auf das Ergebnis unserer theoretischen Untersuchung annehmen, dass auch in der routinemässig durchgeführten Reflexionsseismik das Spektrum der reflektierten Wellen wesentlich durch den Geschwindigkeitsanstieg in der Verwitterungsschicht bestimmt wird. Damit ist jedoch keineswegs gesagt, dass dieser Anstieg das allein bestimmende Element für das Spektrum der beobachteten Wellen ist.

Die Autoren sind der Fa. PRAKLA, Gesellschaft für praktische Lagerstättenforschung G.m.b.H., Hannover, für die gewährte Förderung zur Durchführung der Untersuchung zu grossem Dank verpflichtet.

LETTER TO THE EDITOR

Dear Mr. Editor,

The Relationship between Seismic Amplitude and Weight of Charge

Over the years seismic prospecting parties have fired charges of many different weights in many different locations. On at least some of the resulting records it should be possible to obtain a measure of the seismic amplitude produced per unit weight of charge. And by analysing a large number of records, obtained with a wide variety of charge weights, it should be possible greatly to minimise the very large effects due to shot hole variations and so obtain a reliable estimate of the relationship between seismic amplitude (A) and charge weight (W). I am only aware of one paper which presents such information (Gaskell, 1956) though several studies have been published of the ground motion due to quarry blasting. The most recent of these appears to be that of Habberjam and Whetton (1952). It is not certain, however, that the quarry blasting data are strictly relevant to seismic prospecting, for the shots are usually fired in relatively shallow holes and the mechanism for the production of seismic energy may be appreciably affected by the proximity of the quarry face.

The table below shows some results of mine together with those of Gaskell and those of Habberjam and Whetton. An analysis of covariance shows that Habberjam's value for n is probably not significantly lower than the others (variance ratio at about the 10% level). Whether we do, or do not, consider the quarry blasting results it seems clear that the amplitude of seismic ground motion is closely proportional to the first power of the weight of charge fired, and not to the square root of the weight as might first be thought.

Values for n in the formula $A \propto W^n$

Range of Charge in Pounds Weight	n	S.D. of n	Number of Shots	Wave Type	Source
2½-300	1.12	.107	58	Refracted	O'Brien
20-200	1.11	.067	4	Refracted	Gaskell
4-198	.88	.053	45	Direct ?	Habberjam & Whetton

Overall mean for all data = 0.99 ± .18

Weighted mean excluding Habberjam's data = 1.11 ± .06

A simple explanation for this relationship is provided by adopting the established hypothesis of an "equivalent radiator" (e.g. Sharpe, 1942; Gaskell, 1956) and applying the theory of Blake (1952) for the radiation of elastic waves from a spherical cavity dilating in a solid medium.

The "equivalent radiator" may be defined as the surface around the charge which devides the rock into two parts. An inner part in which the stresses exceed the strength of the rock and an outer part in which infinitesimal strain theory may be applied.

Gaskell (1956) has reported that the volume of the cavity produced by an explosion is directly proportional to the weight of charge fired, and if we assume that the volume of the equivalent radiator is directly proportional to the size of the cavity, we may deduce that its radius is proportional to the cube root of the weight of charge fired.

The graph shown was drawn for Blake's theory, and it shows how the amplitude of ground motion, for a given frequency spectrum, varies with the volume of a dilating sphere. It may be seen, for those values of x (radius multiplied by wave number) which are normally encountered in seismic prospecting, that the amplitude is proportional to the cube of the radius and therefore to the first power of the weight of charge.

The results in the table are for measurements on 'direct' and critically 'refracted' waves. Recent measurements of mine on the variation with charge weight of the total seismic energy produced indicate that the law applies to all the wave types observed, as would be expected.

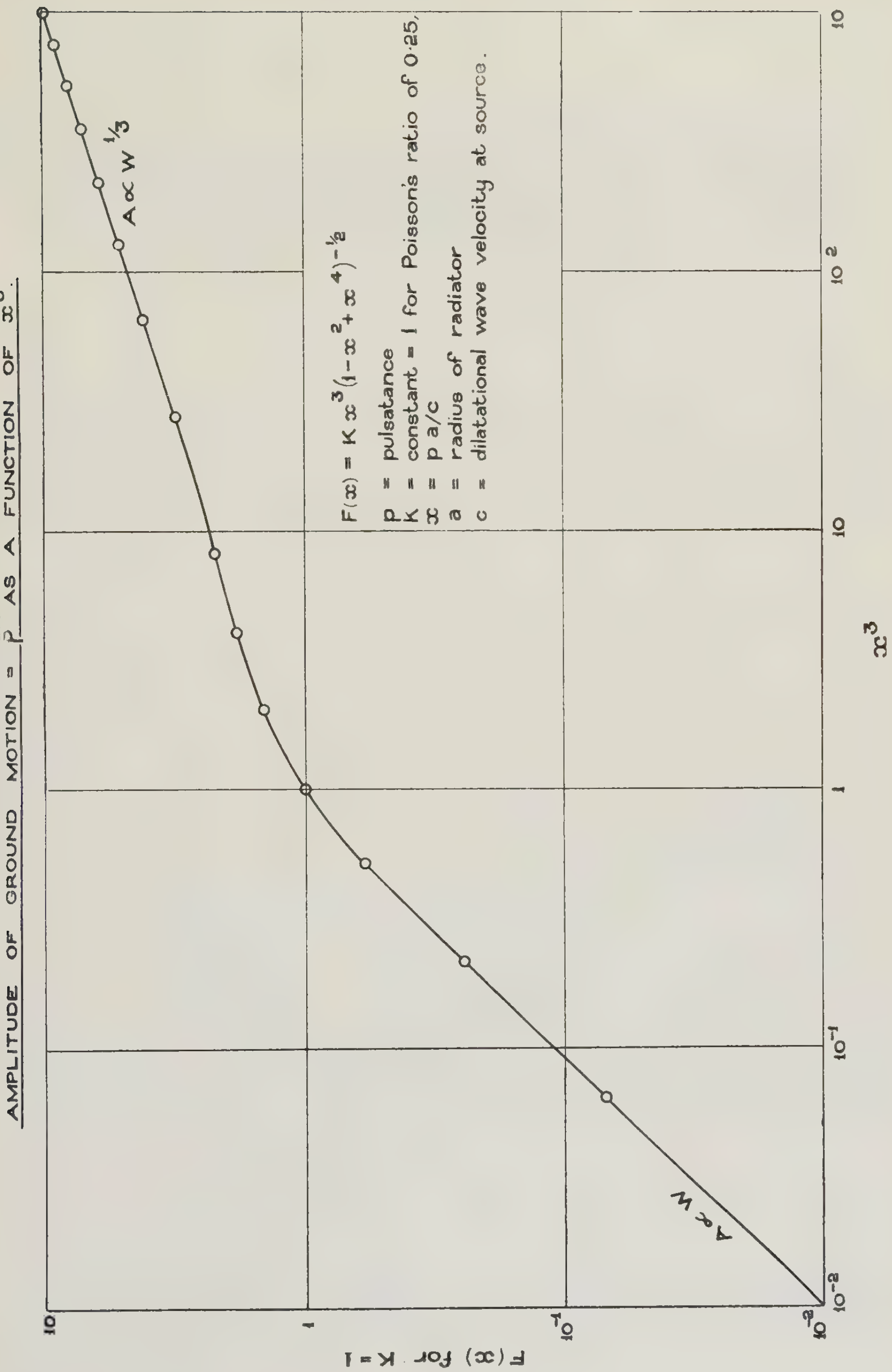
The purpose of this letter is twofold. Firstly to request other workers to present observational data on the variation with charge weight of the amplitude of seismic ground motion (especially for reflected waves). And, secondly, to point out the relevance of Blake's theory.

It would be of great interest to measure ground motion for values of x greater than one, for then we would expect the amplitude to vary as about the cube root of the charge weight. These values would occur for the very large charges that are used in first arrival refraction shooting and for points very close to small charges, where the frequencies are high.

It should also be possible to check the validity of the hypothesis of a closely spherical radiator. This is especially desirable in the light of Heelan's work (1953).

I am indebted to the Chairman of the British Petroleum Company for permission to publish this communication.

P. O'Brien,
British Petroleum Co., Ltd.,
Nr. Newark,
Notts., England.



AMPLITUDE OF GROUND MOTION = $\frac{F(x)}{p}$ AS A FUNCTION OF x^3.

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ABSTRACTS OF PAPERS PRESENTED AT THE TWELFTH MEETING OF THE EUROPEAN ASSOCIATION OF EXPLORATION GEOPHYSICISTS, HELD IN BRUSSELS, 5-7 JUNE 1957.

R. Saint and J. Nicaise, *Activité géophysique dans la partie nord du Bassin de la Cuanza (Angola).*

The exploration of the Cuanza Basin was begun in 1952, with the simultaneous use of surface geology, geological drilling, gravimetry and reflection seismics. The application of the latter method presented certain difficulties (thick weathering zone) which were partly eliminated by using multiple shot holes and geophones. The different methods used have permitted to delineate economically the zones of greatest interest for the location of drill holes. In this folded region, sometimes complicated by the presence of numerous faults and by diapirism, the "Missao de Pesquisas de Petroleo" has so far detected two productive anticlines: Benefica and Luanda.

D. Reyre and J. M. Vallet, *Etude de dômes de sel au Gabon (Afrique équatoriale française).*

The paper gives a historical account of the geological and geophysical research concerning two particularly typical salt domes: those of N'Daminzé and Ozouri.

The N'Daminzé dome is situated in the savannah zone of the western basin of Gabon. The geophysical survey began with a large scale gravimetric campaign. The limited density of measurements actually disclosed great anomalies only connected either with the basement or with large movements of the basin. Next a telluric reconnaissance campaign was executed. This method revealed a series of high resistivity anomalies, one of the most important being centered on the lake of N'Daminzé. The discovery of these anomalies led to a new gravimetric campaign and simultaneously to semi-detailed seismic work. The detailed gravimetry showed at N'Daminzé a large negative anomaly; the seismics showed an important depression centered on the lake and coinciding perfectly with the resistive telluric anomaly. The only possible interpretation was the existence of a salt dome, and this was proved by subsequent drilling.

The Ozouri dome is situated in the zone of the Ogooué delta. The region is extremely marshy, thus making the field work difficult. A seismic survey showed the presence of a high point in the zone of Ozouri which was later detailed by means of fluvial, terrestrial and portable seismic methods. The same district was also explored by a detailed gravimetric survey which revealed a huge negative anomaly. As to the seismic results, which were excellent, they showed at approximately 1,000 m., a very strong reflecting horizon ascribable to the top of the salt and, above, a series of levels showing a complex sedimentation and faulted tectonics. Subsequent drilling led to the discovery of an oil field and the salt was found at the anticipated level.

P. Evrard, L. Jones and Ph. Mathieu, *Présentation des cartes gravimétrique et magnétique de la cuvette congolaise (Congo belge).*

The authors recall the studies which were made in the Central Basin and the Rift Valleys of the Belgian Congo during the years 1952 to 1956. They show the part assigned to geophysical methods for the solution of the given problem and describe the surveys made. In the Central Basin about 6,600 stations were made, covering about 62 square degrees (± 106 stations per square degree). In the Rift Valleys about 220 stations were made over about 17 square degrees (± 13 stations per square degree). In the whole approximately 7,000 stations were surveyed. The authors discuss the gravity survey and the problem involved by the lack of satisfactory planimetric and altimetric maps. The methods and calculations are described briefly. It may be anticipated that the precision of the gravity values will be ± ½ mgal for the North American gravimeter survey and ± 1 mgal for the Norgaard gravimeter survey. The authors then discuss the magnetic surveys made with vertical Askania Gf. 6 magnetometers, the difficulties encountered and the method adopted for the reduction of the measurements. A precision of ± 30 gammas is reached in the vertical component of the magnetic field. As a conclusion, the authors show the map of Bouguer gravity anomalies of the Central Basin and the Rift Valleys, and the map of the vertical intensity of the magnetic field of the Central Basin.

H. A. RÜHMKORF, *Problèmes d'interprétation posés par la prospection sismique en Campine belge.*

Except those from the base of the Tertiary, on the seismograms recorded in the Campine, no reflections occur the pattern of which exhibits any particular or persistent quality. It was therefore necessary to avail oneself of other considerations in the interpretation of the main horizons, such as unconformities and velocity evaluations from refraction shooting. These methods, and also the occurrence of multiple reflections, are discussed.

R. LEGRAND, *Etude systématique de la radioactivité au sol par le Service géologique de Belgique.*

A map is demonstrated showing the results obtained during a systematic study of the ground radioactivity by the measurement of gamma radiation. The map covers an area of 2,000 km², surveyed with a kilometre grid, extending from the Sambre and Meuse to the region of Brussels. The average and most frequent radioactivity in this area is $6\frac{1}{2} \cdot 10^{-6}$ roentgen per hour, but different regions with departing values of the radioactivity occur. The survey has revealed no mineralization of radioactive elements. However, if applied prudently, the radiometric method may be of assistance in the study of certain formation contacts.

J. HOMILIUS and S. LORCH, *Density Determination of Near-surface Layers from Gamma-ray absorption.*

From gamma-ray absorption the density of a homogeneous soil can be determined in situ, without taking samples, down to a depth of 1 m. by a method described in a paper by I. Wendt and checked with satisfactory results (mean error about 1%). A steel rod with some radioactive material at its lower end is pushed into the ground nearly vertically, and the gamma radiation is measured at the surface with two counters at places symmetrical with respect to the rod. As a first step in interpreting the observed effects, the assumption has been made that the counters are infinitesimally small. This paper shows how a theory can be developed without this assumption, the finite dimensions of the counters being taken into account by an integral expression. For this purpose a determination of the dependence of the counting rate on the angle of incidence of the gamma rays is required. The comparison of the experimental with the theoretical results demonstrates that the integral expression is correct. The influence of deviations from the normal geometry of the arrangement (e.g. caused by bending of the probe) on the results is investigated, furthermore the influence of variations of the density with depth. The treatment of the basic problems has been carried through in such a manner that the results obtained may be applied to other absorption methods as well.

J. Goguel and J. Lemoine, *Etude de l'atténuation de l'influence des anomalies superficielles dans le calcul de la dérivée seconde de la gravité.*

In order to eliminate the effect of smoothing due to the use of a finite number of grid points, the second derivative is computed by integrating the product of g with a convenient continuous function, which yields the second derivative to the extent to which the first terms of the Taylor expansion of g represent its value correctly. By applying this method to the anomaly caused by an isolated mass, and to that caused by a homogeneous half plane, it is shown that, if the result obtained is interpreted as if it really were a second derivative, erroneous values for the depth and the mass are obtained. If the real depth of the mass is small, a too large apparent depth is obtained. In the case of a half plane the use of a system of grid points gives the same result. These considerations permit the rational choice of the method of computing the second derivative, such that the effects of too shallow mass irregularities are attenuated.

W. Domzalski, *Some Problems and Results of the Aeromagnetic Surveys.*

A brief description of the procedure usually adopted for ascertaining the accuracy of aeromagnetic data is given as a background to the discussion of factors which affect this accuracy. These factors fall mainly into two groups: spatial positioning, i.e. relation to the ground surface, and effects contributing to the observed relative magnetic values. The evaluation of the observed anomalies in terms of the most probable causes and the anomalies themselves are directly influenced by the amount of the available control of factors mentioned above. The effects of various factors, such as plan positioning, height keeping, diurnal drift, are discussed, the arguments being based on theoretical and practical premises. In the second part of the paper a number of examples are given, showing the results obtained over geologically known areas. An attempt is made to show that although limitations exist as in any other geophysical method, they vary, all other factors being equal, with the scope of the survey and its purpose. Finally, an appeal is made for an exchange of data of a general nature, which could help in the evaluation of changes in the magnetic field which affect observations.

J. M. Graulich and L. Koenigsfeld, *Application de la méthode magnétique à l'étude de structures géologiques.*

The presence of horizons of magnetite in the Devillien phyllites of the Stavelat Cambrian massif led the authors to make a detailed geomagnetic survey of the Grand Hallaux Devillien massif. The survey of the southern part of the massif is now complete, and the authors are already able to draw the following conclusions:

1. In this massif two magnetite zones exist. The upper is found near the top of the Devillien. The lower is in the Stampe, and at some places it splits into two.
2. The quartzites of the Hourt, which up to the present have been thought to be the base of the formation, are in fact a large lens situated between the two zones of magnetite phyllites.
3. The Devillien formations form the sedimentary base of the Revinien, so that their appearance at the surface is not due to a tectonic window.
4. The tectonics of the Devillien formations are very simple, they are mostly gently dipping with some small unimportant steep structures.
5. Furthermore, the magnetic survey has proved the existence of numerous radial faults.

P. N. S. O'Brien, *The Variation with Distance of the Amplitude of Refracted Waves.*

Published in full length in the present issue of Geophysical Prospecting.

Y. Ledoux, *Quelques exemples de diffraction en sismique-réfraction. Application à la détermination des vitesses verticales.*

The progresses attained in recent years in seismic refraction recordings allow a more systematic study of secondary arrivals. In a zone of disturbed tectonics, a considerable part of the recorded energy seems to originate in diffraction phenomena caused by anomalies in the velocity of the marker or of the overburden (faults, local heterogeneities). Some characteristic examples are presented and schematically explained. A more elaborate analysis of branches of diffraction time-distance curves leads, in favourable cases, to a new method of calculation of offsets and vertical velocities, independent of those usually applied to the determination of these parameters.

D. Malmqvist, *The Geophysical Case History of the Kankberg Ore Deposits in the Skellefte District, North Sweden.*

About 8 km. north-west of the well-known Boliden Mine in Northern Sweden lies a small ore deposit, Kankberg. Until now the Kankberg ore deposit is not exploited. It will probably have only little economical importance compared with other mines in the Skellefte District, but from a geophysical point of view it is an occurrence of great interest because there were some difficulties in localizing the principal ore body and in getting sufficient information about its shape by means of geophysical methods. After the first measuring campaign of the area in 1931 with a geo-electrical method, three boreholes were drilled, one of which intersected an ore lense of pyrrhotite. Later on, it could be shown that this was only a small ore lens at the footwall side of the principal ore body. This first indication has naturally drawn special attention to that deposit, and a few geophysical methods have been tried, also at a later stage when most of the conditions concerning the form and size of the different ore bodies were more or less known through holes drilled in the area. Besides a brief description of the geological conditions, the paper presents some results of the various geophysical methods used in the area. As much as possible the results are presented in the same order as the methods were practised in the field. In this manner it seems easier to understand the problems at different stages of research. From a geophysical point of view, the Kankberg deposit is a case of rather complex nature, and it is only by the use of many different methods in connection with a gradually better understanding of known parts of the deposit that new impulses to further investigations could be obtained.

G. Törnqvist, *Some Practical Results of Airborne Electromagnetic Prospecting in Sweden.*

In 1956 a total profile length of about 10,000 kilometres was surveyed in Sweden by a new airborne electromagnetic method. The purpose of the survey was to direct ground parties to areas where conducting ore bodies (sulphides, etc.) might be found and to eliminate barren ground. In this method a rotating electromagnetic field is used and the variations in both the real and imaginary components of the applied field are measured. The airborne work can be done with one plane towing a bird on a long cable or with two planes without cable connection. The two-plane method has proved to have definite advantages over other methods, as shown by practical examples. The relation between the magnitude of the anomaly over background noise in relation to the flying altitude and the transmitter-receiver distance is shown, as well as different types of anomalies obtained. The use of this airborne method for the mapping of shallow structures in oil field terrains is discussed. The equipment for the ensuing electromagnetic ground investigations is briefly described and examples are given of anomalies obtained.

H. Braekken, *Electromagnetic investigation of conductive structures.*

Electromagnetic methods for the investigation of conductive geologic structures are briefly reviewed. On the basis of material from field surveys, laboratory model studies, drilling and drifting it is demonstrated that detailed investigation of both individual conductive ore bodies and more extended conductive mineralizations may be made by suitable electromagnetic methods. Under favourable conditions the structural pictures resulting will closely agree with actual findings in subsequent mining work. It is shown how the exploratory drifting of a new ore body could be planned on the basis of an electromagnetic investigation, supported by the findings from a few diamond drillings.

R. BORTFELD, *A Method of Dip Correction for Expanding Spread Velocity Measurements.*

A method is discussed which takes account of the dip of the reflecting interfaces by applying corrections to the square of the travel times. The determination of the angle of dip is the last step in the computational work, not an intermediate one based on a preliminary value of V. Finally, the application of the method of least squares to the time-corrected values is discussed.

P. MASSON and H. TACHET DES COMBES, *Aspects de la prospection sismique en Egypte, au Sinaï et dans le Golfe de Suez.*

From March 1955 until July 1956 the International Egyptian Oil Company conducted a seismic survey in Sinai and the Gulf of Suez. The water work was complicated by the presence of reefs and by rough seas. In shallow water a swamp technique adapted to local conditions was used. The overall structure of the area is that of a series of faults downthrown towards the centre of the Gulf. The oil traps are anticlines, fault traps and pinch-out traps. The interpretation is complicated by numerous faults, facies changes, dips of about 20°, unconformities, lateral changes in velocity and a Plio-Pleistocene cover which is 1600-2500 m. thick. It proved difficult to identify good marker horizons. In the interpretation migrated time sections were made, and various time depth scales used to calculate depths. It proved possible to map the Belayim field, situated partially on land and partly in the sea, and to discover other structures in the vicinity, some of which are now being drilled.

T. R. GOEDICKE, *New Techniques and Areas of Interest in Marine Oil Prospecting.*

This paper describes some of the areas of the world where interest in marine oil possibilities is centered, and the new methods used to explore these areas. Both geological and geophysical methods are used, aided by the science of oceanography. Studies of ocean floor sediments are carried on by coring with piston corers, bottom samplings by dredging or grab sampling devices, and direct examination of outcrops by diving geologists.

Examples of co-operation of oceanography and geophysics are discussed. Great improvements have been made in offshore seismic methods. Marine seismic surveys can now be carried out at one third of the cost per mile as compared to land seismic surveys. Some of the factors which influence the rapid and highly efficient offshore seismic surveys are the introduction of floating seismic cables, and the introduction of new types of seismic detectors.

New methods of interpretation of geophysical data have contributed much to the understanding of the structural geology beneath the continental shelf. These methods fall into two categories. The first is that of new methods of recording, such as magnetic recorders and special cameras (Reynolds camera, variable density cameras and variable area cameras). The second is that of analysis and presentation of data, including automatic data reduction. These methods are discussed in some detail.

C. R. COLLIN and H. SANSELME, *Recherche des isanomales représentatives par étude statistique sur une carte des résistivités.*

It has been found by experiment that the values of the apparent resistivity determined by a field survey in a given sector, follow the log-normal law of Laplace-Gauss. Based on this observation, the authors have worked out a method of determining the values of the isanomaly lines on the map, by which the anomalies of interest to the geologist are brought out more clearly. The resistivity map treated in this manner provides a better representation of the local geology.

H. FLATHE, *Geoelectrical Investigations on Clay Deposits in Western Germany.*

Geoelectrical resistivity measurements by means of the four-point method were recently employed in the search for and delimitation of clay occurrences in Western Germany. Information is given on results of such investigations in the lower-rhenish border districts. Fundamental considerations on the possibilities and limits of the application of the resistivity method on clay deposits are also included.

F. MOSETTI, *Analyse périodique pour fonctions de deux variables et application aux cartes géophysiques résiduelles.*

The theory of the periodical analysis of functions of one variable is extended to functions of two variables. The resulting selection schemes can be utilized for the calculation of the regional values of the function, and to the selection of residual anomalies. This method is applied to the development of geophysical maps. The analogies with regional field methods and second derivatives method are discussed.

J. C. BELSHÉ, *Establishing the Secular Variation of the Magnetic Field in Britain from Archaeological Remains.*

R. MEISSNER, *Errors and Corrections in connection with Seismic Surveys in Rough Topography.*

The errors involved in the orthodox plotting methods usually employed for seismic reflection surveys in areas with rough topography are analyzed. The main causes of error are near-surface variations of the velocity in and below the weathering layer, and the influence of the rough topography itself in some usual but incorrect plotting methods. Different ways to eliminate these and other errors are discussed and illustrated by figures. The best results are generally obtained when depths are plotted from a horizontal reference surface and, if possible, a special time correction is added by means of a horizon in the upper layers which is known to be sectionally plane.

J. CHASTENET DE GÉRY and H. NAUDY, *Sur l'interprétation des anomalies gravimétriques et magnétiques.*

The anomalies of gravity and terrestrial magnetism are of similar theoretical nature (Newtonian potential) and, from the standpoint of interpretation, show certain analogies though revealing different physical properties of the ground. If hypotheses of geological origin can be made as to the form of the structure, the method indicated by the authors enables their validity to be tested. For this purpose bilogarithmic charts are used; they are similar in their principle to those in use for the past 30 years by the Schlumberger School for the interpretation of electrical soundings. Charts of this type are shown for different forms of subsurface structure, and for the interpretation of both gravimetric and magnetometric observations.

F. MIKLIČ and D. RAVNIK, *Micro-geoelectrical Determination of the Bed-rock Configuration of a Carst Basin.*

The extremely variable thickness of the clay which covers a carst basin, was determined. Special attention had to be given to funnel-like outlets of underground water channels, which are covered with clay and soil, and now invisible. This task called for at least one depth determination in an area of 200-400 square metres. A total of 45,000 resistivity determinations were made. As the electrical two-layer system, of clay (25 Ohm.m) and dolomite or limestone (800-1000 Ohm.m) is nearly uniform over the whole area, the functional relation between the apparent resistivity, measured with profiling at a constant electrode distance, and the thickness of the clay could be determined. This method of depth determination with resistivity profiling is only possible if the resistivity of the clay is equal over the whole area. To determine the influence of the weather, measurements at a base station were repeated daily. Over the covered funnels neither the method of depth determination, mentioned above, nor electrical sounding gave correct results. Although Iso-ohms show the depths too shallow, they gave the shape of quite irregular funnels very exactly. The comparison between geoelectrical data and 180 boreholes shows the advantages of resistivity methods with regard to efficiency, reliability and costs.

F. F. EVISON, *The Pulsed Vibrator as a Seismic Source.*

Various seismic sources have been suggested as possible alternatives to the dynamite explosion, and some of these, notably the falling weight and the eccentric machine, have found some application to special problems. In the study of seismic wave propagation it is sometimes useful to vary the frequency or duration of the radiated wave, and this control can be readily achieved with an electrically driven moving-coil source. Such a vibrator also has practical uses by virtue of the very short impulses that can be obtained, and because it radiates shear as well as compressional waves. The power generated is small because of the inefficient transfer of energy to the ground, but recently published theory contributes much to an understanding of this problem.

H. J. JONES, *Processing of Seismic Magnetic Data in Central Offices.*

The most important instrumentation development of recent years in the seismic exploration industry has been the widespread adoption of magnetic recording. By proper utilization of magnetic recording equipment, seismic exploration crews can effect improvements not only in field data collection operations, but also in analysis and interpretation. Complicated analysis equipment facilitating the application of rapid automatized data processing methods may be located in central offices handling the output of several field crews. The seisMAC system, a digitally programmed time delay unit, permits preparation of time-corrected seismograms in reproducible form. Other electronic apparatus provides flexible filtering, mixing, and compositing. A special seismic section plotter can be used to present analyzed data in a variety of forms on seismic cross-sections. This paper describes the seisMAC, the seismic section plotter, and related central office equipment, and presents typical illustrations of the data analysis. Future potential of magnetic recording and central office processing, and possible new avenues of research and development are also discussed. Considerable emphasis is placed on the limitations, as well as the advantages of these new techniques.

F. MUIR, *Geophone Pattern Connections and a Fundamental Problem in Reflection Seismology.*

Although some attention has been paid to the manner in which geophones should be arranged in patterns, there has been little or no discussion of the related problem of how the geophones should be interconnected within the patterns. The present paper first analyzes the two most common methods of connection, and then discusses the design of the geophone-amplifier link. Finally, it examines the relation of these considerations to the more general problem in reflection seismology of reconstructing the acoustical impedance column from the seismogram.

A. GROSJEAN, *A propos de la prospection géophysique de la Campine belge.*

Since the first boreholes were drilled it has been known that the coal deposits do not subcrop against the Upper Cretaceous unconformity over the whole of the Campine area.

In the north-eastern part of the basin the multicoloured Permo-Triassic marls and sandstones reach such a thickness that the cost of mining the coals becomes prohibitive. On the evidence obtained so far from drilling, the southern boundary of the 'red rocks of the Campine' remains highly problematical. After recalling the various hypotheses which have been made about these formations, the paper presents the picture given by a recent seismic survey. It appears that there is a sedimentary ridge complicated by horst and graben structures. The example has a general significance in that it shows that conclusions based on a few boreholes may be incorrect, if the extrapolations cannot be supported by geophysical methods.

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

376. *Extrapolation Formulae Adaptable to Desk and other Types of Digital Computers.*
V. L. Jones, Geophysics, Vol. 21, No. 4, pp. 1047-1054, Oct. 1956.

The advent of high-speed digital computing machines requires extrapolation and interpolation methods which do not involve central differences and time-consuming tabular information. Extrapolation and interpolation formulae meeting these requirements are developed. These formulae are applicable to the desk calculator as well as to punched-card programming systems for electronic-digital computers. Some applications of the usefulness of these formulae are noted in connection with the preparation of gravity and magnetic maps. Their usefulness may likewise be extended to other types of geophysical and experimental data where the time required to obtain computed results is an economic factor.

377. *Direct-Coupled Thermocouple Amplifiers for Measurements in Geophysics and Meteorology.*
H. J. Albrecht, Geofis. Pura e Appl., Vol. 34, No. 2, pp. 196-206, May-Aug. 1956.

Following a brief discussion of known methods of electronic amplification, this paper describes new thermo-couple amplifiers using junction-type transistors, and their theoretical and practical design. The apparatus amplifies a thermo-couple voltage or other input signals of any impedance such that an ordinary pointer-type galvanometer or recorder can be used as indicator. The problem of temperature compensation has also been dealt with. Details of two transistor amplifiers are given as examples. In conclusion geophysical applications are mentioned.

378. *Post War Developments in Geophysical Instrumentation for Oil Prospecting.*
D. T. Germain-Jones, J. Sci. Instr., Vol. 34, No. 1, pp. 1-8, Jan. 1957.

Noteworthy advances have been made in geophysical apparatus for oil prospecting purposes over the past twelve years. Highly sensitive apparatus for accurate registration in an aeroplane of anomalies in the earth's magnetic field is being employed with considerable success. Gravimeters weighing only 5 lb. and measuring changes in the earth's gravitational field with an accuracy of the order of 1×10^{-8} g are in widespread use. Highly portable low frequency seismic apparatus will register with ease refracted waves up to distances of 20 miles, and seismic reflection equipment of complex design, but rugged and portable, will record reflections of various frequencies from dephts of many thousands of feet. Routine seismic surveys are conducted from ships over water-covered areas, and for accurate location purposes on surveys over prospects under the sea it is customary to employ radio surveying aids. The recent introduction of magnetic recording for seismic surveys offers wide scope for improvements in the seismic techniques; and new methods of displaying the recorded information are likely to help greatly the process of interpretation. Remarkable ingenuity has been shown in the development of radioactive and other forms of well-logging devices.

SEISMIC — GENERAL

379. *Conference on Methods of Seismic Exploration of the Russian Platform.* (In Russian). I. Kupalov-Yaropolk, Akad. Nauk S.S.S.R. Izv. Ser. Geofiz., No. 3, pp. 290-293, 1955.

A conference was held on the problems in exploration for oil in the Russian Platform. Devonian oil-bearing strata are found at dephts of 1,600-2,000 metres covered by Carboniferous formations that may be as much as 1,500 metres thick. Salt domes have very sloping contours, so that the time differences in the arrival of the waves reflected from the roof of the dome and from its flanks are less than 0.001 sec., or much less than the differences in time of arrival caused by slight variations of the relief and by accidental heterogeneities of upper layers.

The following were recommended as the best measures for improvement of results: use of seismic waves with higher frequencies than usual; multiple geophones in spreads of 75 metres long; and use of filters. Numerous individual problems in individual surveys are also described.

(From Geophys. Abstracts 162, U.S. Geol. Survey).

380. *Characteristics of Explosives for Marine Seismic Exploration.*
J. J. Jakosky & J. Jakosky, Jnr, Geophysics, Vol. 21, No. 4, pp. 969-991, Oct. 1956.

The results of preliminary studies and large-scale field tests in California are described. These studies are part of an investigation to develop an explosive which would overcome some of the disadvantages of black powder, which now is the only explosive permissible for offshore exploration in California.

Special instrumentation was developed for recording the pressure-time curves from underwater explosions.

The predominant characteristics of these curves have been related to seismic record quality and the destruction of fish and other marine life. The experimental studies have shown that non-lethal explosives are available which will give record quality and operating costs comparable to the conventional dynamites and which are superior to the black powders.

381. *New Exploration Tool: The Continuous Velocity Log.*
E. M. Denton, Oil & Gas J., Vol. 54, No. 81, pp. 224-227, 230, 234, 19th Dec. 1956.

The results are reviewed of continuous velocity logs from more than 100 Canadian wells. Their former use has been in seismic depth determinations, in identifying reflections and in making for a better understanding of the actual mechanics of reflection generation. The present article shows how they are currently used in the quantitative determination of porosity, the qualitative detection of hydrocarbons, and (in some cases) the actual location of fluid contacts.

SEISMIC — INSTRUMENTAL

382. *Seismic Waves from a Transducer at the Surface of Stratified Ground.*
F. F. Evison, Geophysics, Vol. 21, No. 4, pp. 939-959, Oct. 1956.

Vibration impulses of variable frequency and duration have been generated by means of an electrically excited vibrator and the resulting seismic waves recorded at the ground surface along a 200 ft. traverse. The first arrivals were refractions from the water table and a deeper clay-siltstone interface, and these checked with the results of a standard refraction survey. The amplitudes of displacement of the refracted waves varied in each case with approximately the inverse square of distance, the critical distance was marked by a discontinuity of amplitude. Two later impulsive arrivals recorded within 50 msec. of the first were interpreted respectively as a transformed reflection from 85 feet depth and an ordinary compressional reflection from 200 feet depth. A dispersive Rayleigh wave gave an independent estimate of the shear velocity and thickness of the surface layer. Aircoupled waves of frequencies 70.8 c.p.s. and 330 c.p.s. were recorded and have been related to the first- and third-mode Rayleigh wave respectively.

383. *Piezoelectric Transducers.*
A. C. Dobelli, Acustica, Vol. 6, No. 4, pp. 346-356, 1956.

A brief review is presented of the properties and parameters of the most widely used piezoelectric materials, some of which are given in terms of equivalent circuits; next some of the considerations that should be given to the choice of materials and dimensioning of the element for particular applications. A few piezoelectric crystals are characterized which, although not used on a commercial scale, are nevertheless of scientific interest. In conclusion, some references are given to some recent developments in the field of piezoelectric polycrystalline ceramics.

SEISMIC — FIELD TECHNIQUE

384. *Backscattering of Sound from the Sea Surface: Its Measurement, Causes and Application to the Prediction of Reverberation Levels.*
R. J. Urick & R. M. Hoover, J. Acoust. Soc. Am., Vol. 28, No. 6, pp. 1038-1042, Nov. 1956.

Using two transducers—one for transmitting, one for receiving—mounted so as to be rotatable in a vertical plane and suspended from a buoy, measurements have been made of the backscattering of sound pulses from the surface of the sea as a function of grazing angle between 5 and 90 degrees, wind speed between 3 and 18 knots, and pulse length. When converted to a scattering coefficient per unit area, the results provide some hints as to the processes by which sound is scattered by the ocean surface, and give the basic data for computing the reverberation to be expected with transducers of arbitrary beam width and orientation.

385. *Seismic Waves from a Transducer at the Surface of Stratified Ground.*
F. F. Evison, Geophysics, Vol. 21, No. 4, pp. 939-959, Oct. 1956.

Vibration impulses of variable frequency and duration have been generated by means of an electrically excited vibrator and the resulting seismic waves recorded at the ground surface along a 200-ft. traverse. The first arrivals were refractions from the water table and a deeper clay-siltstone interface, and these checked with the results of a standard refraction survey. The amplitudes of displacement of the refracted waves varied in each case with approximately the inverse square of distance, the critical distance was marked by a discontinuity of amplitude. Two later impulsive arrivals recorded within 50 msec. of the first were interpreted respectively as a transformed reflection from 85 feet depth and an ordinary compressional reflection from 200 feet depth. A dispersive Rayleigh wave gave an independent estimate of the shear velocity and thickness of the surface layer. Aircoupled waves of frequencies 70.8 c.p.s. and 330 c.p.s. were recorded and have been related to the first- and third-mode Rayleigh wave respectively.

386. *New Seismic Technique Promises Better Results in Difficult Areas.*
Oil & Gas J., Vol. 54, No. 81, p. 267, 19th Dec. 1956.

In West Texas the original weight-dropping technique has been modified to generate more seismic energy and to improve signal-noise ratio. This is done by using an adapted earth-moving four-wheeled tractor, which can support a considerably heavier weight, and which (by the even distribution of the tractor's weight about the position of the drop) eliminates certain undesirable vibrations set up by the truck-mounted weight.

SEISMIC — INTERPRETATION

387. *The Effect of Topography on Near-Surface Velocities.*

W. Baillie & T. Rozsa, Geophysics, Vol. 21, No. 4, pp. 960-968, Oct. 1956.

Fictitious seismic anomalies sometimes result from the use of inadequate techniques in making the surface corrections. The effect of topography on the velocities of the underlying layers, commonly referred to as load effect, is a factor which is generally neglected in routine seismic interpretation. The importance of analyzing the load factor is illustrated by an actual example in which a fairly attractive seismic anomaly is shown to be entirely due to velocity variations associated with surface topography. A method of correcting for load effect is discussed.

388. *On the Reliability of Harmonic Analysis of Seismograms.*

A. Korschunow, Geophysical Prospecting, Vol. 4, No. 3, pp. 303-309, Sept. 1956.

Since harmonic analysis of seismograms seems to become more familiar in the interpretation of seismic data, the author presents the results of a thorough check analysis. Following a fixed scheme, one seismogram is analysed by means of a mechanical analyser (system Mader-Ott). Standard deviation of Fourier co-efficients is examined, and scattering in phase values is discussed. At the best, in the range of maximum amplitudes of the spectrum, the method yields 6% in phase scattering. At the worst, on either side of the spectrum, 13% are obtained. Generally 8% have to be taken into account. (Percentages in periods of partial-waves of the analysis!). The results are in accordance with former routine analysis (Korschunow, 1955).

389. *Unexpected Waves Observed in Fluid-Filled Bore Holes.*

J. E. White & H. H. Frost, J. Acoust. Soc. Am., Vol. 28, No. 5, pp. 924-927, Sept. 1956.

Simple computations explain the following causes of unusual wave observations in fluid-filled bore holes.

(1) A square-topped pressure pulse, generated by a broken-off slug of water suddenly rejoining the main column.

(2) Reversal of the pressure break because the wave along a steel casing is often the first arrival.

(3) A negative pressure observed at the bottom of an uncased well, having a relation with elastic constants of the fluid and solid,

and (4) Initial upward motion of a geophone hanging in a bore hole.

SEISMIC — THEORY & RESEARCH

390. *A Theorem Concerning Anisotropy of Stratified Media and its Significance for Reflection Seismics.*

T. Krey and K. Helbig, Geophysical Prospecting, Vol. 4, No. 3, pp. 294-302, Sept. 1956.

It is proved that horizontally stratified media, the various materials of which do not differ in their Poisson number can be considered as isotropic for reflections of a small dip when taking into account quasi-longitudinal waves which have to be reckoned with in practice. Approximating the surface of the wave by an ellipsoid would, however, result in considerable errors.

Moreover, curves are presented allowing practical calculations for steeper dips to be made.

391. *Simple Form of the "Sing-Around" Method for the Determination of Sound Velocities.*

G. W. Ficken, Jnr. & E. A. Hiedemann.

An arrangement for the determination of sound velocities in liquids by means of measuring pulse repetition rates is described which, although very simple, allows an accuracy of better than 1%.

392. *Properties of the Waves Propagating in Elastic Media Analogous to those of Electromagnetic Waves.* (In Russian).
B. Hostinsky, Ceske Akad. ved a umeni Rozpravy, Trida 2, Rocnik 61, Cast 2, Cisclo 25, 1951, (1953).
Mathematical analogies are established between the properties of spherical waves propagating in a homogeneous isotropic perfectly elastic medium and electromagnetic waves in a perfect insulator free of electric charges.
(From Geophys. Abstracts 162, U.S. Geol. Survey).

393. *Velocity of Elastic Waves Propagated in Media with Small Holes.*
Y. Sato, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 30, pt. 3, pp. 179-190, 1952.
Elastic constants and velocity of propagation in media with small holes have been calculated following the method developed by Mackenzie. Convenient expressions for practical use are developed for both empty holes and for holes filled with liquid. The velocity of propagation in a heterogeneous medium cannot be determined from the weighted harmonic means of the velocity of two component substances, one an elastic medium and the other a liquid.
(From Geophys. Abstracts 162, U.S. Geol. Survey).

394. *Velocity of Elastic Waves Propagated in Media with Small Obstacles.*
Y. Sato, Tokyo Univ. Earthquake Research Inst. Bull., Vol. 31, Pt. 1, pp. 1-18, 1953.
A solution is obtained for the velocity of elastic waves in a medium with small solid obstacles (for example, gravel), assuming that the obstacles are spherical and of the same size, small in volume compared to the whole medium, that the displacement and stress components are continuous at the boundary surfaces, and that the wavelength is larger than the diameter of the obstacles. Conclusions regarding bulk modulus and rigidity are similar to those for the medium with small holes.
(From Geophysical Abstracts 162, U.S. Geol. Survey).

395. *The Determination of the Relationship between the Velocity of Propagation of Elastic Waves in Specimens of Rocks and Unilateral Pressure Applied to them.*
Yu. V. Riznichenko & O. I. Silayeva, Akad. Nauk S.S.S.R. Izv. Ser. Geofiz., No. 3, pp. 193-197, 1955.
Rock samples were placed under pressures up to 1000 kg/cm., and elastic oscillations were excited in them both parallel and perpendicular to the direction of applied pressure by an ultrasonic, seismoscope supplied with piezoelectric transducer. Time was measured to ± 0.2-0.5 microsecond. Velocity was measured to ± 1%. Increase of the pressure produced an increase in seismic velocity in all specimens except a few such as gypsum concrete. The increase was in some cases up to 35%. The increase of seismic velocity in the direction parallel to the direction of the applied pressure differed from that in the perpendicular direction.
A detailed description of the setup of the experiments is given, and results are shown graphically.
(From Geophysical Abstracts 162, U.S. Geol. Survey).

GRAVITY — GENERAL

396. *The Establishment of Primary Gravity Bases in Canada.*
M. J. S. Innes and L. G. D. Thompson, Dominion Observatory Ottawa Pubs., Vol. 16, No. 8, pp. 281-310, 1953.

397. *The Danish Gravity Reference Stations.*
S. E. Saxov, Denmark Geod. Inst. Meddel., No. 25, 1952.

398. *Gravity Measurements in the Maritime Provinces.*
G. D. Garland, Dominion Observatory Ottawa Pubs., Vol. 16, No. 7, 1953.

399. *Gravity Profile over the Hogs Back Fault.*
W. Domzalski, Mining Mag., Vol. 91, No. 2, pp. 73-82, 1954.

400. *Gravity Study of Corsica.* (In French).
P. Lejay & S. Coron, Acad. Sci. Paris Comptes Rendus, Vol. 237, No. 7, pp. 447-450, 1953.

GRAVITY — INSTRUMENTAL

401. *Photographic Recording of Earth Tides with a Gravimeter.* (In German).
R. Brein, Deutsche Geod. Komm. Veroff., Reihe B, No. 21, pp. 3-12, 1954.

A photographic method of registration developed for the North American gravimeter can be adapted for use with other gravimeters with optical reading devices with a scale. The curves are nearly drift free.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

GRAVITY — INTERPRETATION

402. *Combined Analysis of Gravimetric and Magnetic Anomalies and some Palaeomagnetic Results.*
A. Landbak, Geophysical Prosp., Vol. 4, No. 3, pp. 226-235, Sept. 1956.

An attempt is made to interpret some magnetic anomalies in Denmark and Northern Holland. As the thickness of the non-magnetic sediments in the areas is large, the interpretation must depend mainly on computational procedures, i.e. a combined analysis of gravimetric and magnetic anomalies, assuming that the two kinds of anomalies originate in the same body.

The mathematic basis of these computations is presented, and from this conclusions are drawn about both direction and intensity of the magnetism in the underlying rocks.

403. *Gravimetric Reductions with Electronic Computers.*
T. J. Kukkamäki, Isostatic Inst. Pub. No. 30, 1955.

Use of electronic computers for determining topographic and isostatic reductions has been suggested by Heiskanen. The globe is divided into compartments bounded by meridians and parallels, and the elevations of these compartments are evaluated once and for all. In the reductions of different stations the elevations of the same compartments can be used. Integration over a compartment limited by meridians and parallels leads to formulae too complicated for practical calculations, so a method of numerical integration is necessary. For that purpose a formula is derived for the attraction of a vertical mass-line, which represents the mass in a frustrum of a cone between elevations or depths in question and which has the apex in the centre of the earth.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

404. *Modern Methods of Studying Gravity and Magnetic Anomalies.* (In Italian).
L. Solaini, Milano Seminario Mat. e Fis. Rend., Vol. 24, pp. 1-20, 1954.

A critical discussion of the methods of interpreting gravity and magnetic anomalies based on calculation of first and second vertical derivatives and upward and downward analytic continuations.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

405. *On the Vertical Gradients of Gravity and their Computing Formulae.* (In Japanese with English Summary).

M. Kato, Butsuri-Tanko (Geophys. Expl.), Vol. 7, No. 3, pp. 128-139, 1954.

A discussion of the first vertical derivative in gravity interpretation and formulae for computing first and second vertical derivatives.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

406. *On the Determination of Density by Nettleton's Method.* (In German).

K. Jung, Erdöl u Kohle, Vol. 8, No. 6, pp. 401-402, 1955.

The procedure suggested by Jung for the determination of density, and by Bortfeld, can lead to erroneous results when the determinant formed from the coefficients of the normal equations introduced by Jung is equal to zero. In other words, the density of the ground varying from element to element of the terrain under consideration must not be a linear function of the co-ordinates of the corresponding element.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

407. *Negative Isostatic Anomalies of Sedimentary Basins. Attempt at Interpretation of the Isostatic Map of the Paris Basin.* (In Italian).

C. Coron, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, fasc. 9, pp. 51-83, 1954.

Calculation of isostatic anomalies for sedimentary basins is discussed in some detail, particularly compensation (Airy) for light masses lying below the geoid. The resulting correction is applied to the isostatic map of the Paris Basin, using available geologic data. The residual anomalies then reveal the broad features of the deep structure—prolongation of the Hercynian arcs and their position relative to recent anticlines and irregularities in the basin floor. Recent sedimentary basins show weak anomalies, generally negative, and most older formations show positive anomalies. In the absence of exact density values, it is difficult to correlate anomalies with the various formations in any greater detail.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

408. *Interpretative Considerations of a Gravimetric Survey.* (In Italian).

L. Solaini, Riv. Geofis. Appl., Vol. 15, No. 2, pp. 93-104, 1954.

For interpretation of a gravity survey of the Pontine plain near Rome, several maps of vertical gradient, second derivatives, Bouguer anomalies extended downward 500 metres, and residual anomalies are compared. The local anomaly, vertical gradient, and downward extension methods mark important progress over earlier methods of intepretation, permitting greater objectivity.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

409. *Anomalies Produced by Sheetlike Disturbing Bodies.* (In Russian).

Yu. P. Bulashevich, Akad. Nauk S.S.S.R. Izv. Ser. Geofis., No. 3, pp. 270-274, 1955.

Solutions of several special cases of gravitational and magnetic anomalies, using the method of direct determination, are given for anomalies produced on the surface of the earth by a vertical plate of a given thickness buried at a given depth and of infinite extent in either direction, by a plate of variable density, and by a group of vertical plates of different magnetic intensity, and the magnetic anomaly produced by a vertical rectangular prism of finite dimensions.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

GRAVITY — THEORY & RESEARCH

410. *Necessity for the Verification and the Study of the Secular Variation to which the Earth's Gravitational Field is Probably Subject.* (In Italian).
C. Gaibar-Puertas, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Vol. 9, pp. 115-121, 1954.

The close correlation between gravimetric and other geophysical phenomena (magnetic, seismic and geothermal) suggests that the former ought likewise to exhibit two types of variations, not only regular short-period fluctuations, of exogene origin (exemplified by earth tides), but also much larger sucular variations, of endogene origin. Comparison of data from gravity stations all over the world and over as long a period of time as possible seem to show a gradual decrease in the value of g. This subject should be investigated thoroughly; recognition of secular variation of gravity, if it exists, could furnish valuable information on the magnitude, velocity, and direction of displacements of matter below the earth's crust.

(From Geophysical Abstracts 162, U.S. Geol. Survey).

MAGNETIC — GENERAL

411. *Rock Magnetism.*
J. A. Clegg, Nature, Vol. 178, No. 4542, pp. 1085-1087, 17th Nov. 1956.

The speakers in a discussion on "Rock Magnetism" at a meeting of Section A of the British Association on September 4th, 1956, were Prof. P. M. S. Blackett, Dr. A. E. M. Nairn and Dr. J. A. Clegg.

Prof. Blackett traced the history of the subject and described how, in contemporary work, rock magnetism is being used to determine direction and intensity of the geomagnetic field many millions of years ago. He discussed also its application to the question of the relation of the continents to each other and to the geographical poles through the ages.

Dr. Nairn described the work carried out by Dr. Runcorn's team, during the past five years, on rock samples from almost every geological formation in Great Britain and many formations in Europe, South Africa and North America. He discussed the evidence of polar wandering and continental drift.

Dr. Clegg described the palaeomagnetic research carried out at the Imperial College and at Canberra in collaboration with Prof. J. C. Jaeger.

412. *Applications of the Remanent Magnetization of Rocks.*
S. K. Runcorn, Geophysical Prospecting, Vol. 4, No. 3, pp. 221-225, Sept. 1956.

The basic principles of remanent magnetization are stated, and possible applications are discussed in the fields of age determination of rocks, the study of relative movements of continents, and investigation of the thermal history of rocks.

MAGNETIC — THEORY & RESEARCH

413. *Rock Magnetism.*
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414. *Magnetic Properties of Magnetite.*
V. B. Rao, Geophysics, Vol. 21, No. 4, pp. 1100-1110, Oct. 1956.

Studies on hysteresis characteristics of a magnetic sample from Gudur area in South India have shown that the susceptibilities of rocks are mainly dependent on the magnetite contained in them. Variations of susceptibility of magnetite with its grain size, its purity and its distribution in an inert matrix provide the explanation for the enormous range of rock susceptibilities usually encountered.

ELECTRICAL

415. *Resistivity of Sandstones as Related to the Geometry of their Interstitial Water,* by F. M. Perkins, Jnr., J. S. Osoba & K. H. Ribe and
Comments, by M. R. J. Wyllie & A. J. DeWitte.
Geophysics, Vol. 21, No. 4, pp. 1071-1084, October 1956.

It is extremely desirable in the interpretation of resistivity measurements made on porous media containing saline water and hydrocarbons to have at hand a better knowledge of the geometry of the conducting salt water.

One geometric characteristic is the tortuosity of the aqueous phase. A method was devised several years ago for the measurement of the tortuosity of completely brine-saturated sands by the measurement of transit time of ions migrating through the aqueous phase under a potential gradient. This method has been improved and extended to the investigation of the tortuosity of sands containing both brine and oil.

Results obtained to date on a group of sandstone samples containing water and oil indicate that there is a relation between the tortuosity of the aqueous phase, the brine content of the sand, the resistivity of the brine, and the resistivity of the gross sample. These results were used to relate the saturation exponent, 'n', which is customarily used in the interpretation of the electric log, to the tortuosity and apparent cross-sectional area of the electrolyte through which electric current flows.

The paper is followed by a comment which demonstrates that the claim of Perkins et al to be able to measure the tortuosities of porous media experimentally cannot be substantiated, and is therefore unjustified.

416. *Graphical Scales for Mapping Potential Functions.*
I. Roman, Geophysics, Vol. 21, No. 4, pp. 1041-1046, Oct. 1956.

Graphical scales can be prepared and used for rapid determinations of potential field values which depend only on the distances between two fixed points. The method can be applied to determine the potential at the surface of a homogeneous earth due to a current pole at its surface, and to the potential at the surface of the earth, considered as an infinite insulator separated from the surface by a parallel plate of finite resistivity. Portions of two typical scales and two sets of equipotential curves drawn by use of the scales are shown.

417. *The Electrical Resistivity of some Sulphide and Oxide Minerals and their Ores.*
D. S. Parasnis, Geophysical Prospecting, Vol. 4, No. 3, pp. 249-278, Sept. 1956.

The electrical resistivity of various samples was measured by the four point method. The method and its application are briefly discussed. Results are presented in tables which give other relevant data (such as percentage of ore in a given sample).

The paper concludes by giving the approximate limits within which the electrical resistivity of the various ores investigated appears to lie. The feasability of detecting these ores by electrical operations is briefly discussed.

RADIOACTIVE

418. *Prospecting with a Scintillometer.*
G. M. Brownell, Precambrian, Vol. 28, No. 1, pp. 12-17, 1955.
Describes a survey of the main Nicholson vein, Goldfields, Saskatchewan.

419. *Prospecting Local Areas with the Airborne Scintillometer.*
G. M. Brownell & R. J. R. Schaller, Precambrian, Vol. 27, No. 3, pp. 6-12, 1954.
Describes surveys in the Foster Lakes area of northcentral Saskatchewan, the Athabaska region and the Blind River and Baldwin Township areas of Ontario.

420. *Applications and Interpretations of Radioactivity Logs in Southern Louisiana Miocene Sands.*
W. B. Vice, Gulf Coast Assn. Geol. Soc. Trans., Vol. 3, pp. 127-146, 1953.

421. *Radioisotopes.*
D. W. Barnett, Tomorrow's Tools Today, Vol. 22, No. 4, pp. 14-17, 4th Q., 1956.
A short paper whose purpose is to define some of the terms which are used in describing radioisotopes, and to summarize the evaluation of a radioisotope for use in tracer surveys.

422. *Analysis of Radioactive Sources in Aeroradiometric Surveys over Oil Fields.*
A. F. Gregory, Bull. A.A.P.G., Vol. 40, No. 10, pp. 2457-2474, Oct. 1956.
Re-evaluation of published aeroradiometric data obtained in two oil field surveys shows that distinct gamma-ray patterns exist but suggests that these patterns have been incorrectly interpreted. A direct correlation of these patterns can be made with the geological, pedological and hydrological elements of the terrain. It is concluded that there is no direct correlation of surface radioactivity with oil at depth. Thus, it appears that aeroradiometric techniques are of little assistance in the location of outcropping petroliferous rocks which are radioactive.

423. *An Airborne Computer-Controlled Detector for Radioactive Ores.*
E. J. Frank, J. British Inst. Radio Engs., Vol. 16, No. 11, pp. 633-645, Nov. 1956.
In the aerial survey of gamma-emitting radio-active materials, the use of two identical detectors, one trailed vertically below the other, allows automatic computation of the true slope of the signal to height curve. Thus immediate automatic correction for relative altitude variations is possible during flight. The computer incorporates a new multiplier system based on frequency pulse-width multiplication.

MULTIPLY REFLECTED REFRACTIONS IN A SHALLOW LAYER.

BY

P. N. S. O'BRIEN *)

Abstract

A strong late arrival, with several cycles, has been observed in line refraction shooting, for distances ranging from 5000 to 30,000 feet. Using equations given by Officer (1953) it has been possible to establish that this event is a multiply reflected refraction. The conclusive factor was its very large amplitude which was about 60 times that expected for the simple head wave, at the distances involved. The wave-guide was bounded by the surface of the earth and by the base of the Low Velocity layer, at a depth of about 80 feet.

An earlier paper (O'Brien, 1957a) gave a study of the head wave pulse refracted from this interface and the conclusions in the two papers are altogether compatible.

Introduction

In an earlier paper (O'Brien, 1957a) a report was made on some measurements on the first peak amplitude of a pulse refracted from a shallow horizon. It was shown that the observations were in very good agreement with the theoretical geometrical decay (or 'spread factor') for the head wave travelling at the interface between two semi-infinite media. That is, the amplitudes decayed approximately as the inverse square of their distance from the source. This pulse was observed for horizontal distances from the source which ranged from about five times up to a maximum of about fifty times the depth to the refractor. Although this ratio was so high it was concluded that the pulse observed was a true first arrival head wave, and not one of the wave guide pulses predicted by Pekeris (1948) and Officer (1953).

This paper reports on observations made on a late arrival which had closely the same velocity as the first arrival pulse, but which was observed for much greater shot-to-station distances. It is concluded that the measurements indicate that this late arrival pulse is identical with the one predicted by Officer.

The Field Experiment

Records were obtained along a single line and for the same four spreads as described in the earlier paper, but with shot-points (on both sides) at

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*) The British Petroleum Company, Ltd.

much greater distances. This is briefly illustrated in figure 1. As before, geophone stations were 250 feet apart with shot-points usually 5000 feet apart.

The prime purpose of the program was to obtain time-distance data for the first arrivals from deep refractors. To this end conventional equipment was used which incorporated a marked amount of filtering. This, of course, somewhat hindered the amplitude measurements.

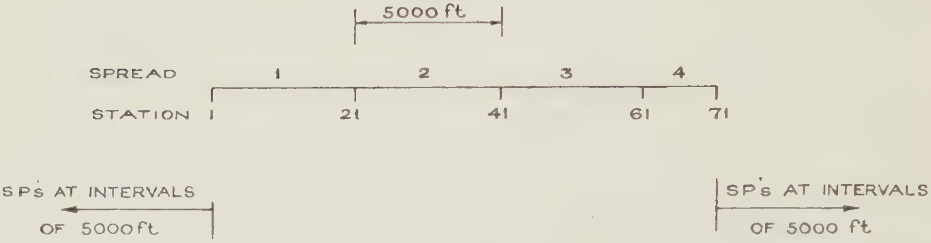

Fig. 1. The Refraction Line

The instruments were calibrated so that trace deflections on the records could be directly related to the amplitude of ground motion at the geophone.

The Field Data

When shooting for first arrival refractions from layers a few thousand feet deep, it was noted that a very prominent late arrival was also recorded. Some typical examples of this are shown in figure 2. The wave velocity of this event was measured on all the records and found to have a mean value of 8850 ± 250 feet per second. This should be compared with the mean velocity of 8600 ± 450 feet per second which was found for the first arrival at shot-to-station distances between 500 and 3000 feet. Amplitude measurements on this first arrival, which comes from a refractor about 80 feet deep, were given in the earlier paper.

Measurements of amplitude and frequency are given here for the late arrivals recorded at distances ranging from 5, 000 to 30,000 feet.

Trace amplitudes were measured as the mean of the three largest peak-to-trough excursions and converted into microvolts input to the amplifiers. For every record mean values were obtained for the individual trace amplitudes and for the corresponding shot-to-station distances. The mean amplitude was obtained by first taking logarithms of the amplitudes of each individual trace on the record, then computing the arithmetic mean of these logarithms and taking its antilogarithm; the last quantity being the required mean amplitude for the record. The same procedure was used to determine a mean shot-to-station distance for the record, i.e. logarithms of the individual station distances

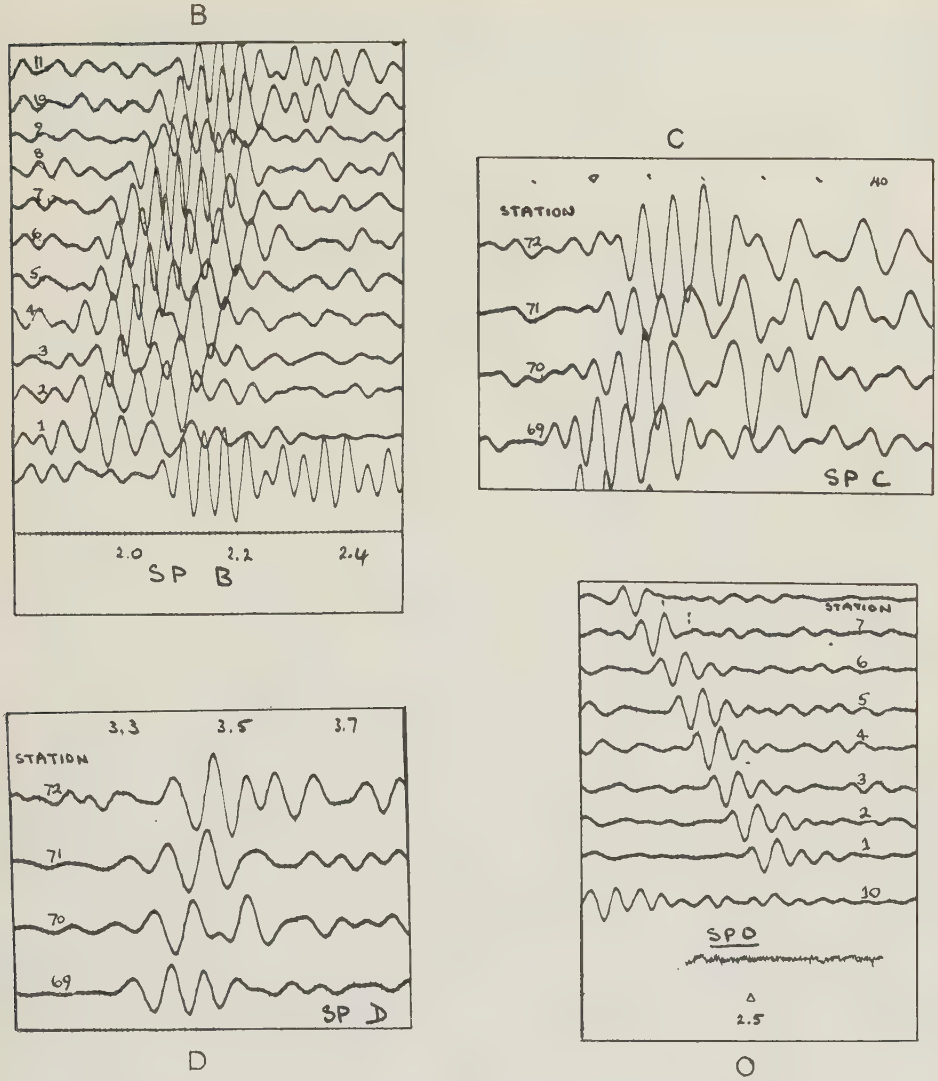

Fig. 2 Some Examples of the Multiply Reflected Refractions

were taken and their mean computed, the antilogarithm of which was the required mean distance. Because of the distances involved these means are valid for either a power or an exponential law for the variation with distance of trace amplitude. Also calculated for each record was the value for m in the formula

$A = Kd^{-m}$ where A = observed amplitude in microvolts,
d = shot-to-station distance,
K, m = constants.

The values for the means and for *m* are given in table I. Table II gives the mean values for *m* over each of the four spreads of geophones, the means being obtained by weighting the individual values according to the grade of the event from which it was obtained. The weights were in the ratios 5 : 4 : 3 : 1 and corresponded to the grades 'Very Good', 'Good', 'Fair', 'Poor'. Events graded 'Doubtful' were not used. The overall mean for *m* is 1.47 ± 0.99.

TABLE I

Amplitude and Distance Data

Stations	Mean Distance From S.P. in Feet	Mean Amplitude in Microvolts	Charge Weight in Pounds	m	Standard Deviation of m	Grade
1 - 17	11,800	1484	150	3.5	0.9	Very Good
1 - 23	7,225	3549	60	3.6	0.3	Very Good
1 - 7	9,300	997	60	5.8	1.0	Good
1 - 10	14,100	675	100	1.8	1.0	Fair
1 - 8	19,700	722	150	2.8	1.4	Fair
1 - 11	24,375	415	300	6.6	1.3	Doubtful
24 - 31	18,875	612	200	11.2	2.8	Doubtful
21 - 43	12,400	2455	100	1.0	0.6	Fair
25 - 41	7,850	2060	60	2.3	0.7	Poor
22 - 27	9,375	1021	60	—0.9	1.1	Doubtful
22 - 28	19,375	159	150	1.2	4.8	Poor
41 - 63	17,425	2422	150	2.0	0.5	Very Good
41 - 62	12,750	997	100	2.4	0.5	Poor
55 - 61	8,850	859	60	—3.4	0.9	Doubtful
62 - 72	28,750	590	300	—1.9	3.2	Very Good
62 - 72	23,750	950	300	—1.0	1.4	Very Good
62 - 72	21,325	1080	150	—2.0	1.6	Very Good
62 - 72	16,225	2082	80	—1.6	1.5	Good
63 - 72	13,875	2604	50	1.4	0.7	Very Good
62 - 68	16,750	296	100	0.5	4.8	Poor
62 - 72	26,250	720	213	—2.11	4.51	Very Good

TABLE II

Mean Values for m in the Relation
(Amplitude) $\propto$ *(Distance)*$^{-m}$

Stations	1 - 23	20 - 43	40 - 63	62 - 71
m	3.63	1.30	2.07	—1.13

m = 1.47 ± 0.99.

The frequencies on each record were estimated by taking the mean of the peak-to-peak periods. They are presented in table III. The overall mean frequency is 19 ± 1 c/s.

The intercept times obtained by projecting the time-distance graphs back to the origin range between the extremes of —0.19 and +0.90 of a second, and have a mean value of 0.325 of a second. This wide scatter is quite acceptable, for it is known that both the overburden and refractor velocity vary appreciably along the line.

TABLE III

Peak-to-Peak Period

Stations	Mean Distance From Shot-Point in Feet	Mean Peak-to-Peak Period in Seconds
1 - 17	11,800	.040
1 - 23	7,225	.050
1 - 7	9,300	.040
- 10	14,100	.046
1 - 8	19,700	.043
21 - 43	12,400	.063
25 - 41	7,850	.073
41 - 63	17,425	.048
41 - 62	12,750	.058
62 - 72	28,750	.050
62 - 72	26,250	.049
62 - 72	23,750	.067
62 - 72	21,325	.060
62 - 72	16,225	.057
62 - 72	13,875	.048

Mean Period = (0.053 ± .0025) Seconds
Mean Frequency = (18.9 ± 0.9) c/s.

DEPTH TO THE REFRACTOR AND THE OVERBURDEN VELOCITY

Because of the parity of the velocity of the late arrival, with the velocity of the first arrival for distances from 500 to 3000 feet, it seems almost certain that they must refer to the same horizon. Accordingly, depths were calculated from the first arrival time-distance data which were supplemented by special close interval refraction spreads and by deep hole velocity surveys.

In the earlier paper it was stated that the refractor lay at a depth of about 80 feet. While this is generally true a more detailed analysis shows that the refracting horizon rapidly shallows under the northern-most extremity of the line, and is about 20 feet deep under station 10. A vector cable survey in the far northern shot-point, which is 15,000 feet from station 10, indicated that the horizon is still about 20 feet deep but with the much decreased velocity of some 6,600 feet per second.

Disregarding the first few feet of very low velocity material, the overburden velocity—as found at five intervals along the observed portion of the line—was found to vary from about 3000 to about 5000 feet per second. There is no exact knowledge of the overburden velocity under the northern-most shot-points, where it may well be somewhat less than 3000 feet per second. Table IV shows the values for overburden velocity and for depth, as found by the special close interval refraction spreads. Their means are 3750 ± 295 feet per second and 60 ± 11 feet, respectively.

TABLE IV

Depth and Velocity for the Overburden

Stations	Depth Range in Feet	Velocity in Feet per Second
13 - 15	0 - 6	1000
	6 - 20	5000
19 - 21	0 - 5	1000
	5 - 80	4000
41 - 43	0 - 15	1750
	15 - 78	3450
55 - 57	0 - 6	1000
	6 - 70	3300
61 - 63	0 - 15	1250
	15 - 50	3300

DISCUSSION OF RESULTS

From immediate visual inspection of the records it seemed that the late arrival had far too much energy to be a continuation of the head wave which was observed over the first 3000 feet. It was immediately suspected that it might be either a 'normal mode' pulse (Pekeris, 1948) or a 'multiply reflected' refraction (Officer, 1953). The main differences between these events and the head wave pulse are,

1) The spread factor is d^{-1} and not d^{-2},

2) The pulse spectrum depends on the depth to the refractor and on the velocity contrast at the interface.

The normal mode pulse gradually builds up from zero amplitude, is both amplitude and frequency modulated, and reaches a strong maximum in the Airy phase, which travels with a group velocity somewhat less than that of the overburden velocity. The 'multiply reflected' refraction has a sharp onset and is of fairly constant amplitude. Inspection of the observed pulse (see a few examples in figure 2) showed fairly conclusively that the event has a relatively sudden and large amplitude onset which does not lead into the Airy phase, and so is unlikely to be a normal mode pulse.

For a simple one layer case the frequencies in a multiply reflected refraction are given by the equation (equation 44 of Officer).

$$f = [(2n - 1)\ c_1 c_2] \ / \ [4H\ (c_2^2 - c_1^2)^{\frac{1}{2}}],$$

where n = an integer,
c_1 = velocity in the overburden,
c_2 = velocity in the refractor,
H = thickness of the overburden.

As mentioned in the preceding section c_1, c_2 and H all vary along the line, though they appear fairly constant under stations 20-70. If we insert in the frequency equation the previously quoted arithmetic mean values for c_1, c_9 and H we find that

$$f = (17.3 \pm 3.6)\ (2n - 1).$$

The mean peak-to-peak frequency as read off the records is (18.9 ± 0.9) c/s. This is not significantly different from the calculated frequency for the first mode of a multiply reflected refraction. Higher modes would not have been observed because of a pronounced high frequency cut in the recording instruments.

Although the observed and calculated frequencies are quite compatible this is not sufficient evidence positively to identify the event as a multiply reflected refraction. This is because the frequency equation is directly proportional to changes in c and H and our values for these quantities were observed for only a few short intervals of the line; and also because the theory deals with a single fluid layer of constant velocity, and we have ignored the known variation in velocity over the first 10 feet or so of the subsurface which is, of course, solid.

A more reliable guide to the nature of the event is its rate of attenuation. The mean value for m in the equation

$$\text{Amplitude} \ \alpha \ (\text{Distance})^m$$

has been shown to be -1.47 ± 0.99. The standard error of the mean is too large to say with any certainty that its value is significantly less than 2, and so we cannot use this evidence to decide what type of refraction the event may be.

One further test is to use the known rate of attenuation of the first arrival to predict its amplitude at the mean distance for the late arrival, and to compare this predicted amplitude with that observed for the late arrival. In order to compare more accurately these two values allowance has to be made for the variation in charge weight between the many different shots. This has been done by taking the amplitude directly proportional to the first power of the weight of charge fired (O'Brien, 1957b), but, as may be seen later, the conclusion will not be much affected whatever relationship is assumed.

The logarithmic means for the amplitude of the late arrival per pound weight of charge and for the shot-to-station distance are 8.86 μ V and 14,600 feet, respectively.

In figures 3-6 of my previous paper, values were given for the first peak amplitude of the first arrival. These give a mean of $11 \pm 3\mu$ V/1b. wt. of charge for a distance of 2000 feet. This value has been reduced to the distance of 14,600 feet by taking the first peak amplitude to vary as (distance) -2.16 which is the rate of attenuation reported in the earlier paper. We then get an amplitude of 0.15 μ V/1b. wt. of charge for the head wave at the distance of 14,600 feet. The ratio of the mean energies for the two events may well be greater than that indicated by the ratio of the amplitudes, for although the late event measurements is from peak-to-trough, there are several well developed cycles in it, whereas the first arrival seems to have only two cycles at the most. The late arrival amplitude is so many times that predicted for the head wave that there seems no doubt that the event observed is a wave-guide phenomena.

By using equations 11, 12 and 39 in Officer's paper it is possible to predict, for a single frequency, the ratio of the amplitude of the multiply reflected wave to that of the head wave. Using the previously noted values of the velocities and depth, and assuming a unit density ratio at the interface, then, for a frequency of 19 c/s, the reinforced wave should have an amplitude about 50 times as great as the head wave. This figure applies only very approximately to the observed pulses, not only because of all the departures of the field conditions from the simple layer theory, but also because the predominant frequencies in the head wave pulse were somewhat higher than 19 c/s. This last factor will presumably mean we are overestimating the 19 c/s content of the head wave and that we would expect the amplitude ratio to be somewhat less than 50. As we have seen in the previous paragraph the observed ratio is about 60.

It is, unfortunately, not possible to make measurements on the pulse when it first becomes a late arrival. This is because of gross interference with deeper events, over the vital range of distances.

CONCLUSIONS

There seems little doubt that the tests outlined above are sufficient to establish that the late arrival observed was a wave-guide phenomenon, as predicted theoretically by Officer, and observed by him on seismic records obtained at sea. It is thought that this is the first paper to describe such an event on land, though Officer stated that it should be observed in a solid medium.

It is interesting to see what conclusions we could have drawn from the late arrival pulse, if we had had to do without the short distance first arrival information on the head wave. We could have probably established that it was not a simple head wave by extrapolating its amplitude back towards the shot-point with the factor d^{-2} exp. $(-\lambda d)$, where d is the shot-to-station distance and λ is about $\frac{1}{2}db$ per wavelength. This would lead to amplitudes far too great at short distances and so would have indicated that d^{-1} would be a more correct spread factor, thus implying that the event was a wave-guide phenomenon. We could then have used the frequency equation to put limits on the value for the depth to the interface. In our case we could have made a reasonable guess as to the overburden velocity from information in adjoining areas, and so have obtained an actual estimate for the depth.

The frequency equation will never give as accurate values for the depth to an interface as may be obtained by observations on the head wave. But it might well give useful information, which is now disregarded; for instance, in reconnaissance refraction surveying, it could, perhaps, be used to give the gross variation in the Low Velocity layers.

Because the wave-guide pulse does not appear to develop fully for recording distances much less than many times the depth to the interface, it is unlikely that information will be obtained on the deeper refractors, unless the upper bound to the wave-guide is itself well below the surface. Under such a condition it should be possible to obtain information about strata which are too thin to carry observable amounts of head wave energy.

It is also necessary to guard against identifying the wave-guide pulse as a head wave and so mistakenly applying the conventional time-distance interpretation to the determination of either relative or absolute depths. For example, if we had used the mean intercept time of 0.325 of a second, found for the late arrival, we would have obtained a depth of about 6-700 feet for the interface — a value too large by a factor of ten.

Officer's theory applies to fluids. When dealing with solids the problem becomes immediately more complex due to the additional possibility of shear waves. Margery Newlands (1952) and Cagniard (1939) have treated analytically the generalised problem for a source buried within an elastic medium having a single surface layer. But though they treat the problem most fully neither of them appears to have explicitly mentioned those guided waves which travel with the velocity of the lower medium. A simple extension of Officer's ray theory to solids, leads one to predict the possibility of two additional waves of this type. One travels within the overburden with its shear (S) wave velocity, and another travels in the overburden with mixed P and S ray paths. These will have their own frequency equations.

Under our field conditions we might expect that these two additional waves will be of relatively low energy, because of the predominantly compressive motion of the source and the low P to S conversion for the angles of incidence involved.

ACKNOWLEDGEMENT

The author is indebted to the Chairman of the British Petroleum Company for permission to publish this paper, to Mr. G. Bowling for doing many of the calculations, and to Prof. J. McG. Bruckshaw for reading the manuscript.

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THE PULSED VIBRATOR AS A SEISMIC SOURCE *

BY

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ABSTRACT

Non-explosive seismic sources, notably the falling weight and the eccentric machine, have occasionally proved advantageous in experimental and practical seismology in spite of their relative feebleness.

Another alternative is the pulsed vibrator, which offers the advantage of a completely controllable waveform. Recent theory shows that such a source is quite well adapted to the radiation of high frequency waves from the surface of the ground; it is estimated, for example, that in typical circumstances reflections should be obtainable from depths of the order of 200 metres. The theory also shows how resonances may be avoided so as to radiate the impulsive waveform unimpaired.

INTRODUCTION

Since the early days of experimental seismology various types of non-explosive device have been used for generating seismic waves. The outstanding merits of the explosive source were recognised, however, as early as 1849, when Robert Mallet chose gunpowder for his pioneering experiments in Ireland, and from the time of Mintrop's original patent on the refraction method in Germany in 1919 almost the whole of seismic prospecting has depended on dynamite as a source. One has only to contemplate the virtually unlimited energy that dynamite can provide, and the suddenness with which the release of this energy is initiated, to realise that for the great bulk of prospecting work, certainly where depths of thousands of metres are involved, the explosive source is unlikely to find a competitor. At the same time the explosive source is not without drawbacks which in some contexts may even conceivably outweigh its advantages, and there has recently been a growing interest in possible alternatives.

The scope for non-explosive sources is perhaps to be found rather in connection with fundamental studies of propagation phenomena than in prospecting, since such studies can often be carried out on quite a small scale and some relatively feeble source may offer the important advantage of a more controllable signal. Thus transducer sources are being widely used in the recently-developed laboratory technique of model seismology. Likewise the pulsed vibrator to be discussed here was designed primarily to assist small-scale studies of propagation in the ground, particularly of phenomena involving the frequency and amplitude of seismic waves. But, in addition, in modern prospecting attention is being attracted to certain problems to which the explosive source is not well adapted, for example problems requiring the use of very short seismic impulses, as in shallow reflection prospecting. Instances have been reported where marine echo-sounding apparatus has given useful reflections from strata lying beneath rivers and lakes, and the transducer type of source is also proving valuable for acoustic well-logging. It may therefore be timely to discuss the possibility of applying such a source directly to the ground as a radiator of seismic waves for purposes of exploration. This question has been much elucidated by recent theoretical analyses of the behaviour of various idealised types of radiator at the surface of an elastic solid.

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*)Presented at the Twelfth Meeting of the European Association of Exploration Geophysicists, held in Brussels, 5/7 June, 1957.

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Non-Explosive Sources

Before describing the pulsed vibrator it is appropriate to review briefly the other main types of seismic source that have been devised, especially since these are simpler in principle and often more convenient to operate.

The most favoured and probably the earliest alternative source to the dynamite explosion is the falling weight. The simplicity of this source has attracted many experimenters since it was used in 1881 by the earthquake seismologists Milne and Gray in Japan, to observe how the character of recorded tremors varied with the type of ground. In their experiments a weight of some 750 kg was dropped from heights up to 10½ metres, providing an impulse comparable in magnitude to that of the weight-dropping apparatus that has lately found commercial application in prospecting.

Studies of propagation from much smaller weights have been reported from time to time in the Bulletin of the Earthquake Research Institute at Tokyo University, and elsewhere. In a recent paper the character of the impulse produced by this means was investigated with the help of a pick-up built into the weight (Kasahara, 1954), and it was shown that if the ground were covered at the point of impact with a sheet of sponge-rubber 1 cm thick the dominant frequency of the shock was lowered, while with a similar sheet of wood the dominant frequency was raised. This experiment draws attention to a feature that the falling weight and the explosion have in common, and which makes it difficult to exercise control over the radiated waveform, namely that the character of the impulse is largely determined by the nature of the ground at the source.

Truck-mounted weights of several tons have recently come into limited use for prospecting in the U.S.A., particularly in built-up areas or in country where the drilling of shot-holes is exceptionally difficult. The low energy of the signal is partly offset by the use of magnetic tape recorders, by which the records from a number of shocks can be superimposed; but the success of this technique depends on the extent to which similar waveforms can be reproduced in successive shocks.

Being an essentially asymmetrical source the falling weight radiates shear as well as compressional energy, and swinging weights have been found effective as sources of horizontally polarised shear waves (White, Heaps and Lawrence, 1956). A further variant of the falling weight, the sledgehammer, has been successfully used for shallow prospecting in certain areas by D. I. Gough (1952). In general the falling weight appears to produce a waveform not unlike that from small explosions, except that the first arrival does not show such a sudden onset, and since the waveform is complex and tends to vary with distance from the source there may be difficulty in obtaining accurate travel-times.

The other main class of non-explosive source is the eccentric machine, which is used to set up continuous vibrations at frequencies variable up to a maximum of about 50 c/s. For higher frequencies a moving-coil transducer may be used in a similar way. In Germany in the 1930's, eccentric machines were used extensively by the organisation Deutsche Forschungsgesellschaft für Bodenmechanik, with the object of investigating the dynamic properties of the ground from the viewpoint of foundation engineering, and it is in this sphere that the method seems to be most successful. It has obvious applications to the study of soil compaction and also to the design of foundations for industrial machinery, including the design of highways to withstand vibrations produced by heavy traffic. The eccentric machine is an especially convenient means for discovering frequencies at which resonance may arise in the ground. But the interpretation of ground resonance as observed in these early empirical studies was attended by a good deal of confusion; the phenomenon is indeed a complicated one, and since it has an important bearing on the operation of a pulsed vibrator it will be discussed in some detail later.

The theory of the eccentric machine as used in soil mechanics has recently been placed on a sound basis and a detailed account of the present status of the subject may be found in a recent symposium published by the American Society for Testing Materials (1953). As a result of these theoretical advances it is now possible to relate the behaviour of the machine to the elastic constants and density of the ground on which it rests, though caution is still recommended in adopting for practical purposes the values determined in this way.

These applications of the eccentric machine have little to do with radiation of energy in the form of seismic waves. Yet it is a consequence of the well-known theorem of Fourier that whatever one may be able to find out about the ground by means of seismic impulses, as in prospecting, may alternatively be found out by using continuous waves of variable frequency; instead of measuring the travel-time of impulses one measures the relative phase of sine waves. Some few experimenters have indeed worked on this principle (e.g. v. d. Poel, 1943), but beyond finding the velocity of predominant Rayleigh waves and perhaps the thickness of the surface layer (Jones, 1955), the problem of measuring and interpreting relative phases at a large number of frequencies is so involved that there seems little likelihood of a widely applicable technique emerging. Nevertheless a control over frequency, such as is given by the eccentric machine, is an important advantage for fundamental studies, and with the pulsed vibrator an attempt is made to combine this advantage with that of an impulsive source.

A Pulsed Vibrator

The distinguishing feature of electromechanical sources is that in principle they can be designed to radiate waves of any form whatsoever, since the vibratory motion can be made to conform with the exciting voltage or current. The explosive source lends itself least to shallow prospecting because the duration of the radiated impulse can hardly be controlled independently of other features, and the same is true of the falling weight. Such control is readily attainable, however, with electromechanical sources; likewise the radiated wave can be given a dominant frequency which is independently variable. A convenient type of waveform embodying both impulsive and frequency-selective features is provided by the square-enveloped pulse of sine waves. Such waveforms were used, as well as damped wavetrains and continuous vibrations, in an early series of vibrator experiments by Howell, Kean and Thompson (1940).

In a square-enveloped pulse the dominance of the chosen frequency increases with pulsewidth; conversely the impulsive aspect is emphasised as the pulsewidth diminishes, until, when only a single half-cycle is generated, the frequency is of little significance. Either aspect may be the more important in a practical problem, and for fundamental studies a wide choice of waveforms is desirable. The appropriate frequency band for a seismic vibrator is a matter for compromise between the degree of resolution required, on the one hand, and the effect of absorption, which increases with frequency, on the other. Although the vibrator itself is more powerful at high frequencies it seems likely that absorption will encourage the use of the lowest possible frequencies. The present apparatus was designed for pulsewidths in the range 5-100 milliseconds and frequencies of 100-800 c/s. Other experimenters, however, have recently begun tests with marine echo-sounding apparatus operating at frequencies between 6,000 c/s and 16,000 c/s (Zietz and Pakiser, 1957); similar frequencies are used in acoustic well-logging, but there the source and receiver are only a few feet apart.

Details of the vibrator have been fully described elsewhere (Evison, 1953). Briefly, it is a moving coil transducer of the Fessenden type, driven by commutated direct current from an 84 v. bank of accumulators. The frequency is determined by the speed of the commutator, and the pulsewidth by a variable capacitance which discharges through the coil of a series relay switch. Attached to the moving coil of the vibrator is a rigid circular frame which can be either bolted to the ground or used as a piston. When assembled the vibrator weighs about 400 kg, and the peak force developed at all frequencies is 3.6×10^8 dyne. The vibrator has proved an effective source of compressional, shear, Rayleigh and air-coupled waves, and in various types of ground it has produced adequate signals at ranges of around 100 metres and more (Evison 1951, 1953, 1956).

The factors determining the amount of power radiated by a vibrator have been indicated by recent theory, which also throws light on the problem of communicating a pulse waveform to the ground. These are crucial matters for the application of such a source to prospecting, and a discussion of the relevant theoretical results will now be given with particular reference to the apparatus described above.

Power and Range

A vibrator which operates as a piston may be regarded as a rigid disc vibrating normally to the surface of the ground. A useful guide to the performance of such a source is provided by the theoretical studies of Miller and Pursey (1954, 1955) and of Bycroft (1956); some aspects of this theory have been verified by laboratory experiments using foam rubber as the medium (Arnold, Bycroft and Warburton, 1955). The theory refers to sinusoidal vibrations radiated into a homogeneous, isotropic, elastic medium, and an assumption has also to be made about the distribution of force under the disc. Hence one cannot expect too precise a description of the behaviour of a pulsed vibrator applied to the ground, although calculations by Pursey (1956) agree remarkably well with measured values of the power radiated in compressional and shear waves during an early series of experiments by the present writer (Evison, 1951); on that occasion the frequency was 600 c/s and the pulsewidth 20 milliseconds, so that the pulse contained twelve cycles, and the peak power would be virtually the same as for continuous waves.

The theoretical studies cited above are chiefly concerned with small sources, —i.e. such that the circumference of the disc is less than one-half the compressional wavelength,—or with certain multiple arrays of such sources. Where a practical vibrator is applied to competent rock this restriction will usually be satisfied, but the same machine applied to a low velocity layer may not, by this definition, still be small. Most of the ensuing discussion is necessarily concerned with the small source; it should be mentioned, however, that larger sources may turn out to be preferable for some types of seismic work.

The power radiated by a small vibrator can be expressed by a simple formula if some definite value is assigned to Poisson's ratio σ for the medium (Miller and Pursey, 1955). The value chosen here is $\sigma = \frac{1}{4}$; an increase to $\sigma = \frac{1}{3}$ would add about 40 per cent to the power. Thus the radiated power W is given approximately by

$$W=15\ F^2f^2/\rho V^3 \text{ erg/sec}$$

where F is the peak force applied to the ground (dyne)
f is the frequency of vibration (c/s)
ρ is the density of the ground (gm/cm^3),
and V is the velocity of compressional waves in the ground (cm/sec)

Of this power, 6.9 per cent is in the compressional wave, 25.8 per cent in the shear wave, and 67.3 per cent in the surface wave. In many applications, however, the compressional wave will not be at such a disadvantage as might appear, since according to Miller and Pursey (1954) the radiation vertically downwards is wholly compressional, and the compressional wave is at its maximum in this direction. Moreover the surface wave referred to here is not the ground-roll of conventional prospecting, which propagates as a guided wave in the surface layer and acquires its dominant frequency by a process of continual reinforcement; the present surface wave is an ordinary Rayleigh wave having the same frequency f as the body waves, and it can therefore be expected to suffer rapid absorption.

It will be seen that the dimensions of the vibrator base do not enter into the power formula. These can therefore be chosen purely by such practical considerations as the degree of homogeneity of the ground, the tendency of the ground to yield, and the need for adequate rigidity in the base. The power is proportional to the square of frequency, an attractive property which will tend to counteract the greater absorption of high frequencies in the ground, and thus to favour the propagation of very short pulses such as are needed to give high resolution. The power is also proportional to the inverse cube of the velocity of propagation. Thus a vibrator, in contrast to explosive sources, is many times more powerful when operating at the surface of a low-velocity layer than on bedrock.

The amount of power available from the present apparatus may be illustrated by the following case, taking typical conditions for an experiment at the surface of a low-velocity layer:-

$F = 3.6 \times 10^8$ dyne; $f = 200$ c/s; $\rho = 1.7$ gm/cm³; $V = 4 \times 10^4$ cm/sec

Then $$W = 72.0 \times 10^7 \text{ erg/sec}$$

The power W_c in the compressional wave is

$$W_c = 5.0 \times 10^7 \text{ erg/sec}$$

These values are approximately correct provided the radius r of the base satisfies

$$r < V/4\pi f \approx 16 \text{ cm}$$

No direct comparison of this power with that of the conventional explosive source seems possible since there is little information on the seismic power of explosions under prospecting conditions; moreover very different waveforms are involved, that contemplated here consisting of several equal oscillations at the frequency 200 c/s. But some idea of the effective range of the vibrator may be obtained by considering a set of conditions that might be encountered in a shallow reflection survey.

Beneath the surface layer ($V_0 = 4 \times 10^4$ cm/sec, $\rho_o = 1.7$ gm/cm³) suppose a substratum ($V_1 = 20 \times 10^4$ cm/sec, $\rho_1 = 2.0$ gm/cm³), and at depth H(cm) a reflector ($V_2 = 25 \times 10^4$ cm/sec, $\rho_2 = 2.3$ gm/cm³). For simplicity assume uniform absorption over the path of the reflected wave, taking as the coefficient of absorption $\alpha = 0.03$ per wavelength (i.e. 0.26 db per wavelength). This amount of absorption is likely to be reasonable for the substratum, so in effect we are assuming that the surface layer is thin compared with H. Then, neglecting the directionality of the source, and writing $R = \rho V$, the power density ΔW_c of a vertical reflection arrival from depth H is given by

$$\Delta W_c = \frac{W_c}{2\pi (2H)^2} \left\{ \frac{4 R_0 R_1}{(R_0 + R_1)^2} \right\}^2 \left\{ \frac{R_2 - R_1}{R_2 + R_1} \right\}^2 \exp\left(-4\alpha H f / V_1\right)$$

$$= 1.58 \times 10^4/H^2 \exp. (1.2 \times 10^{-4} H) \text{ erg/sec cm}^2$$

Now if we have a surface geophone of sensitivity $S = 0.5$ volt/cm/sec., and if the minimum output that will give a recognisable reflection signal is $v_{MIN} = 10$ microvolt peak (corresponding to a peak particle velocity of 2×10^{-5} cm/-sec), then the minimum useful power density is given by

$$(\Delta W_c)_{MIN} = \tfrac{1}{2} R_o (v_{MIN}/2S)^2$$
$$= 3.4 \times 10^{-6} \text{ erg/sec cm}^2$$

Thus if H_{MAX} is the greatest depth from which a recognisable reflection can be obtained, we have

$$H^2_{MAX} \exp (1.2 \times 10^{-4} H_{MAX}) = 1.58 \times 10^4/3.4 \times 10^{-6}$$
$$= 46.4 \times 10^8$$

Hence $$H_{MAX} \approx 200 \text{ metres}$$

From this example it appears that the pulsed vibrator may be useful for reflection prospecting at shallow levels, where application of the conventional technique has proved difficult. Likewise, the available power should be adequate for investigations on the sort of scale usually found in problems of mining and of foundation engineering.

WAVEFORM

Having established that a useful amount of seismic power may be derived from a vibrator at frequencies appropriate to shallow prospecting, it remains to ensure that such a source can in ordinary circumstances radiate the desired waveform, since the main advantage that a pulsed vibrator can be expected to enjoy over other sources is that of a controlled waveform. A voltage varying in the manner of a square-enveloped pulse is readily produced by the means described above, but this waveform will not be reproduced in the radiated seismic wave unless resonances are avoided in both the electrical circuit and the mechanical system. In the Fessenden type of transducer the electrical role of the moving-coil is that of a short-circuited transformer secondary, and since there is little leakage inductance the electrical reactance is negligible and resonance does not occur. Electrical resonance may also be eliminated in other types of transducer. But mechanical resonance may still arise in a number of different ways.

In general the ground itself, as a continuous and homogeneous medium, has no intrinsic resonance; nor does resonance arise when a weightless disc vibrates at the surface of such a medium. Thus the ground when excited by a vibrator cannot strictly be said to have a natural frequency unless it is stratified. But a low-velocity layer, for example, may resonate at any frequency for which its thickness is equal to an odd number of quarter-wavelengths, and in working with a pulsed vibrator it is desirable to avoid frequencies in the vicinity of any such resonance.

Resonance can occur between the ground and a vibrating disc, however, when the disc has appreciable mass. A rough estimate of the natural frequency of such a system may be based on the static deflection formula of Boussinesq (Arnold, Bycroft and Warburton, 1955). Thus the natural frequency f_o (c/s) is given approximately by

$$f_o = \sqrt{\{Er/2\pi^2 M\ (1-\sigma^2)\}}$$

where E is the Young's modulus of the ground (dyne/cm^2),
σ is the Poisson's ratio of the ground
r is the radius of the disc (cm),
and M is the mass of the disc (gm).

Calculations show that this type of resonance can easily occur in practice within the frequency range in which we are interested. But by making the vibrator base sufficiently light the resonance, at whatever frequency it may occur, can be made as broad as we like, and therefore of negligible effect on the waveform.

The sharpness of this resonance is usually expressed in terms of the dimensionless parameter b, where

$$b = M/\rho r^3$$

ρ being the density of the ground.

It can be shown that if the vibrator base and the ground be regarded as a simple mass-spring system with damping, then for ground with a given Poisson's ratio the parameter b varies inversely as the square of the damping factor. For $\sigma = \frac{1}{4}$ for example, the damping is at least critical if

$$b \leqslant 0.66$$

In practice this criterion is not difficult to satisfy; an adequately rigid base of radius 60 cm was constructed for the present apparatus by bolting a steel plate to a welded angle-iron frame, and gave approximately $b = 0.2$. The mass of the vibrator base also affects the resonant frequencies of a surface layer (Warburton, 1957), but if the above criterion for b is satisfied these frequencies are virtually the same as for a weightless disc.

Having made the vibrator base light one must next take care that the main mass of the vibrator is not excited into resonance with its supports. For the frequencies with which we are concerned this is readily achieved by supporting the mass on rubber machine-mountings. There remains the possibility of resonance between the main mass and the ground, but for an apparatus of the type described here it is clear from a study of the equivalent electrical circuit (Evison, 1951) that any such resonance is heavily damped and will not noticeably affect the waveform.

Thus by observing certain precautions in the design of a pulsed vibrator one may avoid resonances which would be likely to detract from the impulsive character of the waveform. As a consequence, the design differs basically from that of a continuous vibrator, the power and efficiency of which can be greatly enhanced by means of resonance. A resonant vibrator can also be used, by shock excitation, to generate a semi-impulsive, damped wavetrain, but this waveform has no obvious advantage over the explosive impulse for shallow prospecting.

CONCLUSION

The pulsed vibrator is evidently capable of radiating sufficient seismic power to be of use in shallow prospecting, where the advantage of a controlled waveform is greatest. The recent theory provides some guidance for the correct design of a vibrator and for the choice of suitable operating conditions. The theory is still mainly confined to the case of small, steady-state sources on highly idealised media, though Bycroft (1956) has briefly discussed the effect of absorption in the medium and Miller and Pursey (1955) have analysed the circular array of small sources, showing that for a given frequency there is a certain configuration which will minimise the surface wave. It may be expected that further elaborations will follow, thus providing the vibrator with a theoretical description such as could hardly be hoped for in the case of the explosive source. Both this and more extensive experimental studies will no doubt be stimulated if the vibrator is considered to have a future in prospecting.

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DISCUSSION

Mr. Wachhof: Which is the better source for measurements underground (in mines etc.)?

Mr. Evison: Seismic measurements based on the conventional prospecting techniques do not seem to have had much success in underground mines; perhaps the new high-resolution techniques would help here. Of course the chief region of interest in mining is usually within a few hundred metres at the most, so it will often be necessary to use extremely short pulses, and in this event a vibrator source may prove very useful. I have used the pulsed vibrator underground on several occasions and found it perform quite satisfactorily.

In the particular case of coal mines there are circumstances which make it doubtful whether any pulse method can succeed, with problems such as locating faults ahead of the face. Here a more promising approach may be to rely on the dispersive properties of guided waves (Evison, 1955, A coal seam as a guide for seismic energy, Nature 176, 1224-1225). For this purpose the explosive source may be the best.

QUELQUES EXEMPLES DE DIFFRACTIONS EN SISMIQUE-REFRACTION ET LEUR APPLICATION A LA DETERMINATION DES VITESSES VERTICALES *)

PAR

Y. LEDOUX **)

Abstract

The progress in the registration of refraction shots obtained in the last years permits a more systematic study of the secondary arrivals. In zones with disturbed tectonics, a noticeable portion of the received energy derives from diffraction phenomena caused by velocity anomalies in the marker bed or in the overburden (faults, local heterogeneities). Some characteristic examples are presented and schematically explained.

A more advanced analysis of the branches of the travel time curve caused by diffraction leads, in favourable cases, to a new method of calculating the offsets and the vertical velocities, independent of the usual methods for the determination of these parameters.

Sommaire

Les progrès réalisés depuis quelques années dans l'enregistrement des tirs de sismique-réfraction permettent une étude plus systématique des arrivées secondes. Dans les zones de tectonique tourmentée, une fraction notable de l'énergie recúeillie provient de phénomènes de diffraction causés par les anomalies de vitesse du marqueur ou du recouvrement (failles, hétérogénéités locales). Quelques exemples caractéristiques sont présentés et schématiquement expliqués.

Une analyse plus poussée des branches de dromochronique de diffraction conduit, dans les cas favorables, à un nouveau mode de calcul des offsets et des vitesses verticales indépendant des méthodes habituellement utilisées pour la détermination de ces paramètres.

Introduction

C'est à l'observation courante de phénomènes de diffraction sur les enregistrements sismiques que l'on doit la multiplicité des études théoriques publiées à ce sujet. Par analogie entre les lois de propagation des ondes en optique et en sismique, on pouvait s'attendre à l'apparition de diffractions, d'autant mieux observables que leur amplitude relative croît avec la longueur d'onde de la vibration.

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*) Presented at the Twelfth Meeting of the European Association of Exploration Geophysicists, held in Brussels, 5-7 June 1957.

**) Compagnie Générale de Géophysique, Paris.

L'amélioration progressivement réalisée dans l'appareillage d'enregistrement (amplification, filtrage, A.V.C.) a mis en relief l'importance des ondes diffractées; leur effet perturbateur, longtemps considéré comme nocif, a fait l'objet d'une analyse poussée de la part de géophysiciens comme C. H. JOHNSON, C. H. DIX, TH. KREY, C. CONTINI. Un certain nombre de lois importantes se sont dégagées de ces observations; on sait maintenant interpréter correctement, dans la plupart des cas, les diffractions et tirer de leur étude une information supplémentaire du plus haut intérêt sur leur origine (faille, rupture de pendage, etc . . .).

Presque toutes les observations ont porté jusqu'ici sur des films de sismique-réflexion. Or la théorie prévoit qu'en réfraction, où les vibrations sont de période beaucoup plus grande, la diffraction devrait apparaître avec une amplitude relative plus forte qu'en réflexion. S'il n'en a pas été ainsi, c'est que l'enregistrement systématique des arrivées tardives est relativement récent; l'ancienne ,,religion'' du premier départ de forme presque anguleuse, où la milliseconde est obtenue au prix d'une dépense d'explosifs exorbitante, nous a longtemps privé d'une bonne partie de l'information.

Les exemples de films qui sont présentés ici ont pour propos une ,,prise de conscience'' du phénomène et de son importance, plutôt qu'une interprétation théorique complète. Ils ont été choisis pour leur simplicité et leur valeur illustrative, afin de pouvoir servir de guide à l'interprétation de films plus complexes, où les données souvent fragmentaires seraient difficilement compréhensibles sans éducation préalable. On donnera enfin un aperçu sur les éléments qui peuvent se déduire immédiatement des dromochroniques de diffraction: position des failles, valeur numérique des offsets et des vitesses verticales.

EXEMPLES SIMPLES DE DIFFRACTIONS

Rappel de quelques notions élémentaires (Fig. 1)

Le cas le plus simple, couramment résolu (mais avec certaines approximations) dans les manuels, est illustré par la Fig. 1: sondage-réfraction disposé perpendiculairement à une faille de rejet modéré. Le passage de la faille se traduit par une translation parallèle à l'axe des temps de la branche de dromochronique directe, le raccord étant assuré par une portion d'hyperbole; pour le tir inverse, la translation est égale et de signe contraire, sa valeur absolue étant:

$$T = P \cos i/V_1$$

Sur ces seules données, on peut donc calculer le rejet *P* de la faille et, avec une précision moindre, sa position et la valeur de l'offset.

Pour illustrer de façon plus précise la manière dont s'effectue le raccord, l',,hyperbole de diffraction'' a été dessinée sur la Fig. 1 avec ses asymptotes, dont la pente est égale en valeur absolue à l'inverse de la vitesse V_1 du recouvrement, supposé homogène. On notera que les hyperboles correspondant au tir direct et au tir inverse se déduisent l'une de l'autre par une translation parallèle à l'axe des temps, et que la position de la faille est donnée par l'axe commun à ces deux hyperboles.

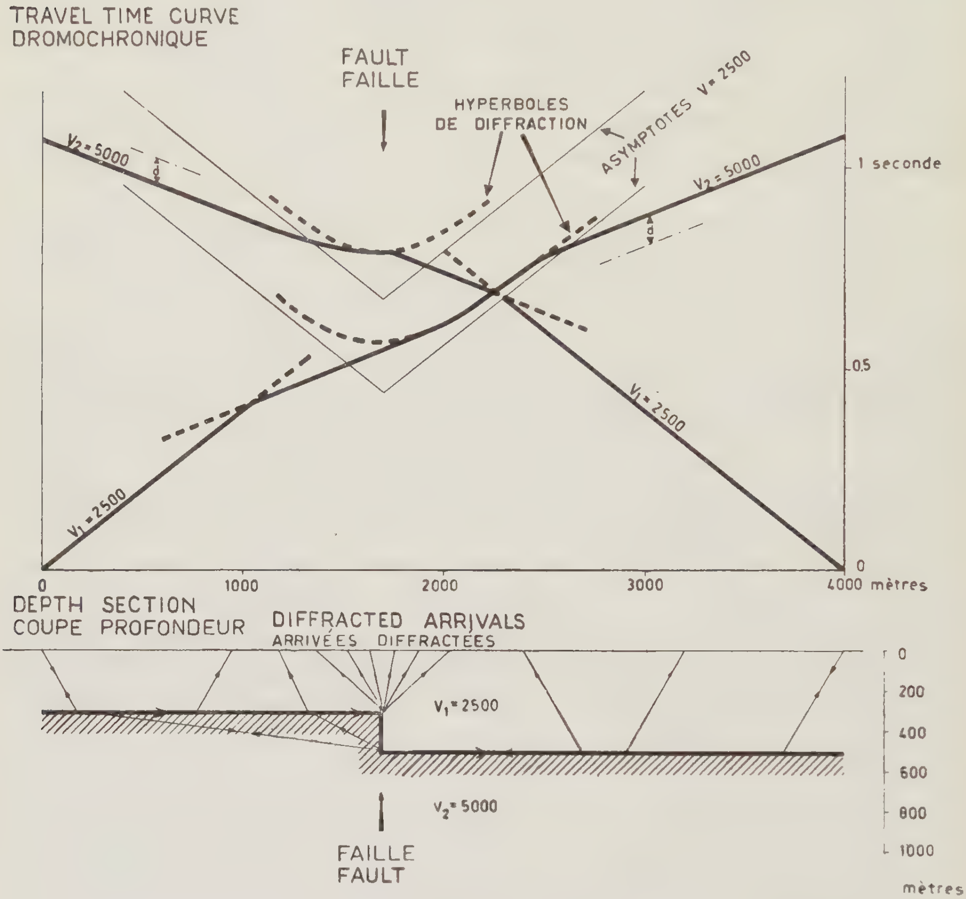

Fig. 1. Dromochroniques d'arrivées premières; cas théorique d'une faille simple.
Travel time curves of first arrivals; theoretical case of a simple fault.

Deux exemples-types d'hyperboles de diffraction

L'enregistrement systématique des arrivées tardives permet souvent d'observer effectivement une portion importante de l'hyperbole (ou plus exactement d'une courbe se rapprochant d'autant mieux d'une hyperbole que le recouvrement est plus homogène).

a) *Tir en ligne* (Fig. 2)

La Fig. 2 reproduit l'enregistrement d'un tir en ligne à partir du compartiment effondré d'une faille: l'énergie diffractée est importante et dessine une hyperbole assez régulière. L'amplitude du phénomène décroît lentement lorsqu'on s'éloigne de la faille, dont la position est définie par l'axe de l'hyperbole.

Le rejet de l'accident est supérieur à 500 mètres et sa profondeur de l'ordre de 3000 mètres: ce qui explique l'ampleur de l'hyperbole de diffraction.

b) *Tir en arc* (Fig. 2 bis)

Nous démontrerons plus loin qu'un élément de profil disposé perpendiculairement à une faille, et tiré dans une direction parallèle à cette faille, peut donner lieu également à une hyperbole de diffraction.

La Fig. 2 bis, tirée d'une publication antérieure de l'auteur, montre un bel exemple de diffraction au passage d'une faille de grand rejet; les deux hyperboles correspondent respectivement aux deux trajets possibles ,,up'' et ,,down'' des ondes sismiques parallèlement à la faille.

Remarques

L'interprétation des deux exemples précédents n'a été qu'ébauchée. Il est clair en effet que la forme réelle du marqueur est beaucoup plus complexe que celle des schémas explicatifs: le bord de la faille n'est pas une arête idéalement aigue; les perturbations que pourraient apporter l'inhomogénéité du recouvrement au passage de l'accident n'ont pas été envisagées.

L'étude qui va suivre se propose d'examiner, sur des exemples, dans quelle mesure les figures expérimentales de diffraction peuvent être assimilées à des cas théoriques simples.

EXPLICATION DES PHENOMENES OBSERVES

a) *Tir en ligne*

Nous nous placerons dans le cas le plus simple: faille de rejet suffisamment grand pour que les arrivées provenant du compartiment effondré ne puissent être observées (Fig. 3).

L'arête de la faille joue le rôle d'une source d'émission d'énergie diffractée.

La dromochronique de diffraction est constituée par une demi-hyperbole dont le grand axe est vertical. On démontre sans difficulté que:

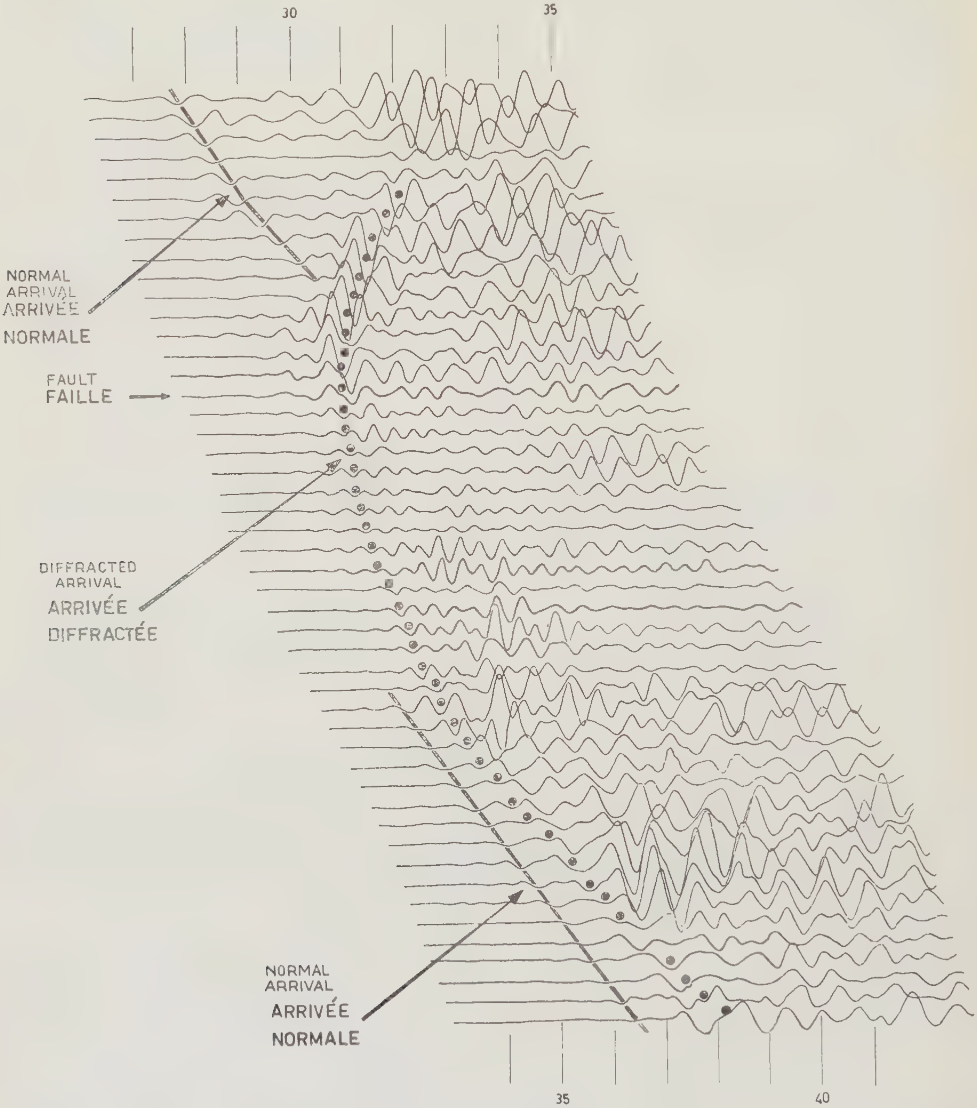

Fig. 2. Exemple de phénomène de diffraction au passage d'une faille; tir en ligne. Example of diffraction at a fault; in line shooting.

1°) L'axe de l'hyperbole donne la position réelle de la faille.
2°) La pente des asymptotes a pour valeur absolue $1/V_1$
3°) La distance horizontale entre l'axe de l'hyperbole et le point de raccord

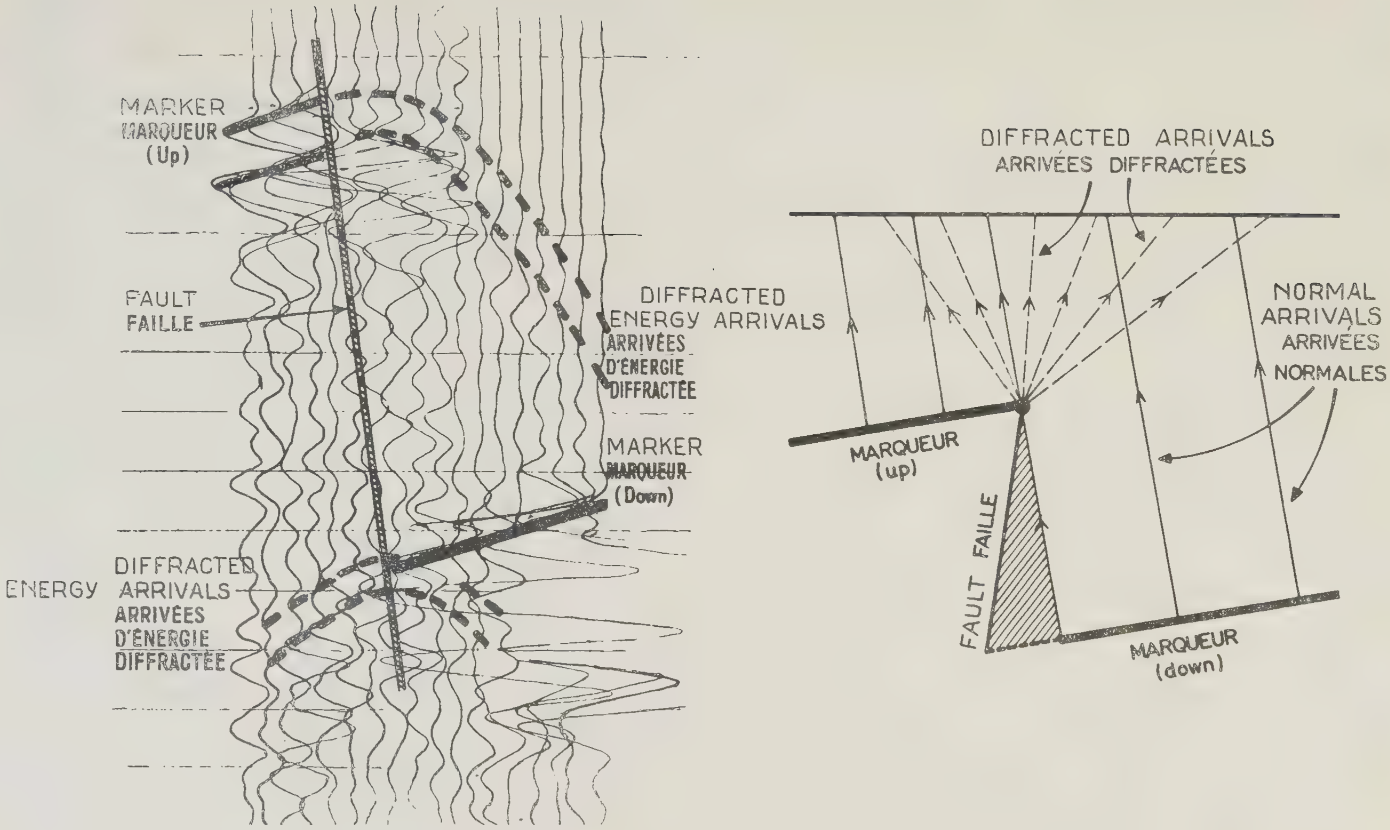

Fig. 2bis. Exemple de diffraction au passage d'une faille; tir en arc.
Example of diffraction at a fault; arc shooting.

avec la dromochronique rectiligne de pente $1/V_2$ est égale à l'offset au sismographe correspondant à ce point.

Soit d'autre part $\Theta_0 = P/V_1$ le temps de propagation verticale entre l'arête de la faille et la surface du sol et Θ le temps oblique correspondant pour une distance X; on a:

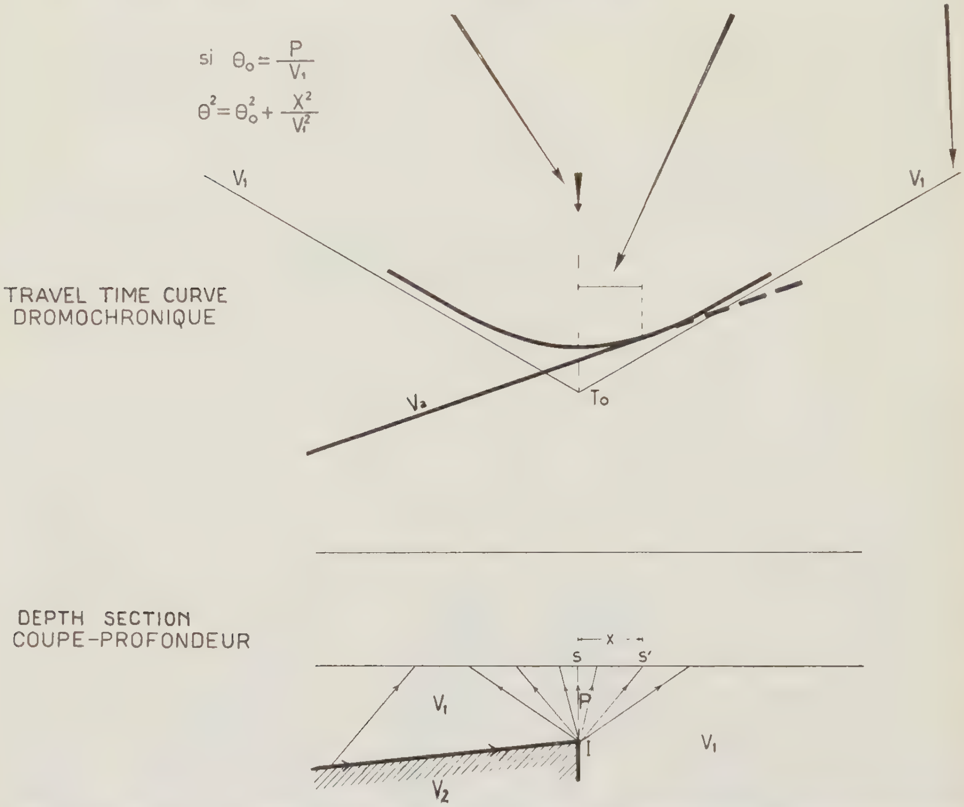

Fig. 3. Diffraction; schéma de principe; tir en ligne. L'hyperbole de diffraction permet de déterminer 1) la position de la faille, 2) la valeur de l'offset, 3) la vitesse V_1.
Diffraction; illustration of principle; in line shooting. The diffraction hyperbola permits the determination of 1) the position of the fault, 2) the offset, 3) the velocity V_1.

$$\Theta^2 = \Theta^2_0 + X^2/V^2_1$$

équation de l'hyperbole de diffraction.

Exemple (Fig. 4)

Cet exemple a été choisi pour son originalité: le marqueur donne lieu à deux arrivées d'énergie successives, caractère bien connu sur tout le périmètre d'étude. Au passage d'une faille, l'hyperbole de diffraction, bien développée, présente le même caractère.

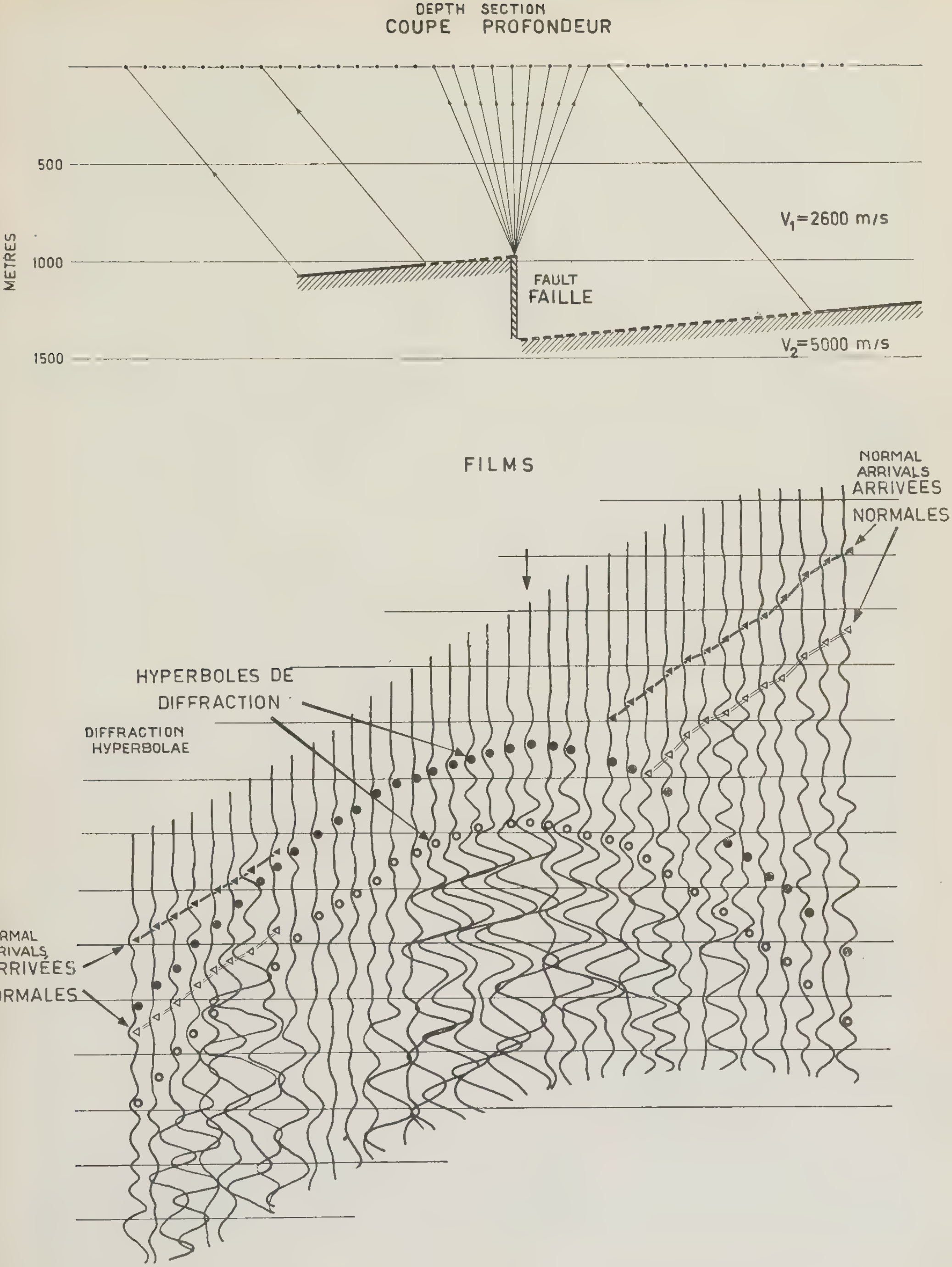

Fig. 4. Essai d'interprétation d'un phénomène de diffraction au passage d'une faille; tir en ligne.
Tentative interpretation of a diffraction phenomenon at a fault; in line shooting.

L'assemblage des films est présenté verticalement pour faciliter la confrontation avec l'interprétation schématique de la faille; de part et d'autre de l'accident, le marqueur est assimilé à un plan incliné, dont la construction est aisée. Mais il resterait, sur la position exacte de la faille, une grande incertitude (plus de 2 kilomètres) si l'axe de l'hyperbole de diffraction ne venait nous fournir cet élément, avec une précision estimée à 200 mètres. C'est là un résultat remarquable. Les informations supplémentaires que l'on peut déduire de la forme de l'hyperbole seront examinées plus loin.

b) *Tir en arc*

Nous supposerons dans tout ce qui suit que l',,arc'' est un élément de profil rectiligne disposé perpendiculairement à la faille, le point de tir étant très éloigné dans la direction de cette faille.

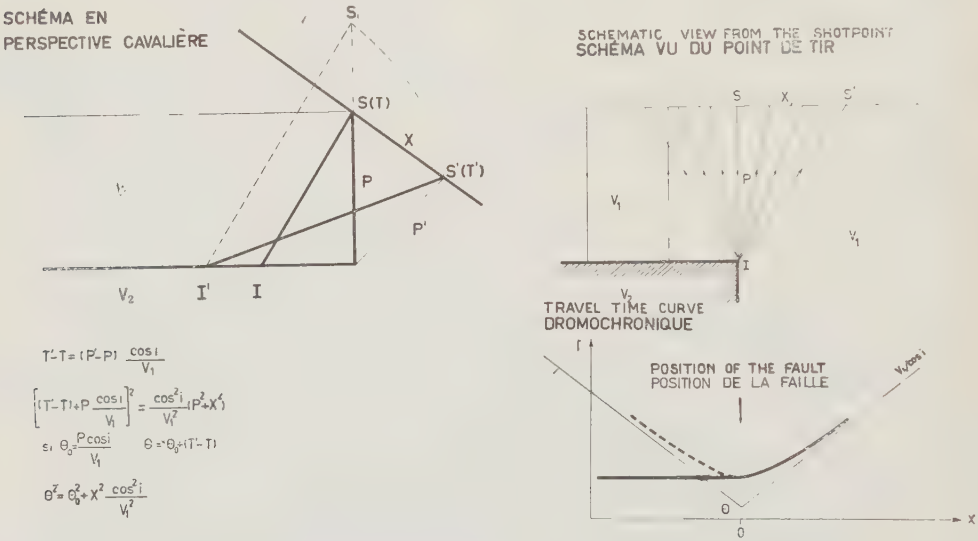
SCHÉMA EN
PERSPECTIVE CAVALIÈRE
S
S(T)
X
S'(T')
P
P'
V₁
V₂
I'
I
$T'-T=(P'-P)\frac{\cos i}{V_1}$
$\left[(T'-T)+P\frac{\cos i}{V_1}\right]^2=\frac{\cos^2 i}{V_1^2}(P^2+X^2)$
si $\theta_0=\frac{P\cos i}{V_1}$ $\theta=\theta_0+(T'-T)$
$\theta^2=\theta_0^2+X^2\frac{\cos^2 i}{V_1^2}$
SCHEMATIC VIEW FROM THE SHOTPOINT
SCHÉMA VU DU POINT DE TIR
S
X
S'
P
P'
V₁
V₁
I
V₂
TRAVEL TIME CURVE
DROMOCHRONIQUE
T
POSITION OF THE FAULT
POSITION DE LA FAILLE
V₁/cos i
θ
0
X

Fig. 5. Diffraction; schémas de principe; tir en arc. L'hyperbole de diffraction permet de déterminer 1) la position de la faille, 2) la quantité $V_1/\cos i$.
Diffraction; illustration of the principle; arc shooting. The diffraction hyperbola permits the determination of 1) the position of the fault, 2) the quantity $V_1/\cos i$.

La diffraction présente dans ce cas une particularité importante: ce n'est plus un point, mais un segment de l'arête qui joue le rôle de source pour les ondes diffractées. Le phénomène est illustré sur la Fig. 5: pour chaque sismographe, le rayon diffracté émergeant forme avec le plan normal à l'arête un angle constant i tel que:

$$\sin i = V_1/V_2$$

Un calcul élémentaire, reproduit sur la Fig. 5, montre que la dromochronique correspondante est encore une hyperbole d'équation:

$$\Theta^2 = \Theta_0^2 + X^2 \cos^2 i/V_1^2$$

$$\text{avec } \Theta_0 = P. \cos i/V_1$$

L'axe de l'hyperbole indique toujours la position réelle de la faille, mais la valeur absolue de la pente de ses asymptotes est $(\cos i)/V_1$, au lieu de $1/V_1$ pour le tir en ligne.

Exemple (Fig. 6)

Il s'agit d'un tir en arc sur un système de failles parallèles affectant un marqueur très rapide (6100 m/s); le recouvrement est formée d'argiles de vitesse moyenne 2850 m/s. Ce fort contraste de vitesses est favorable à l'apparition de phénomènes de diffraction.

On voit immédiatement sur les films plusieurs panneaux de pendages différents; la faille la plus importante produit une hyperbole de diffraction particulièrement caractéristique. Sur la coupe-profondeur, chaque panneau a été „restitué'' dans sa position réelle. Les petits accidents sur la partie droite de la coupe ne donnent pas de diffraction notable, mais leur position, par le jeu de la migration des panneaux, est définie avec une bonne précision. Par contre, la position de la grande faille nous est fournie par l'axe de l'hyperbole de diffraction; en l'absence de celle-ci, l'incertitude serait de l'ordre de 1500 mètres.

Remarques

L'hyperbole théorique se rapprochant le plus de la courbe expérimentale de diffraction a été dessinée également sur la Fig. 6; les écarts entre ces deux courbes sont assez faibles pour être attribués à des irrégularités de surface ou à des interférences entre les ondes normales et diffractées.

Nous reviendrons au paragraphe suivant sur les indications fournies par la forme de l'hyperbole.

Determination Pratique des Vitesses Verticales

Parmi tous les paramètres nécessaires à l'interprétation des films de sismique-réfraction, la vitesse verticale moyenne des terrains de recouvrement est sans doute le plus difficile à atteindre. L'observation des premières branches de dromochroniques sur les sondages réfraction ne saurait fournir que la vitesse horizontale des marqueurs intermédiaires, dont on ne sait a priori s'ils constituent le toit de formations isotropes superposées dans l'ordre des vitesses décroissantes, ou bien s'ils ne correspondent qu'à des intercalations de bancs rapides dans un milieu plus lent. Il n'en ressort donc rien d'autres que des indications, non sans valeur, mais qui ne sauraient remplacer une mesure directe.

La méthode couramment utilisée, en l'absence de mesures dans les forages, consiste à déterminer sur un profil en „double contrôle'' la valeur de l'offset,

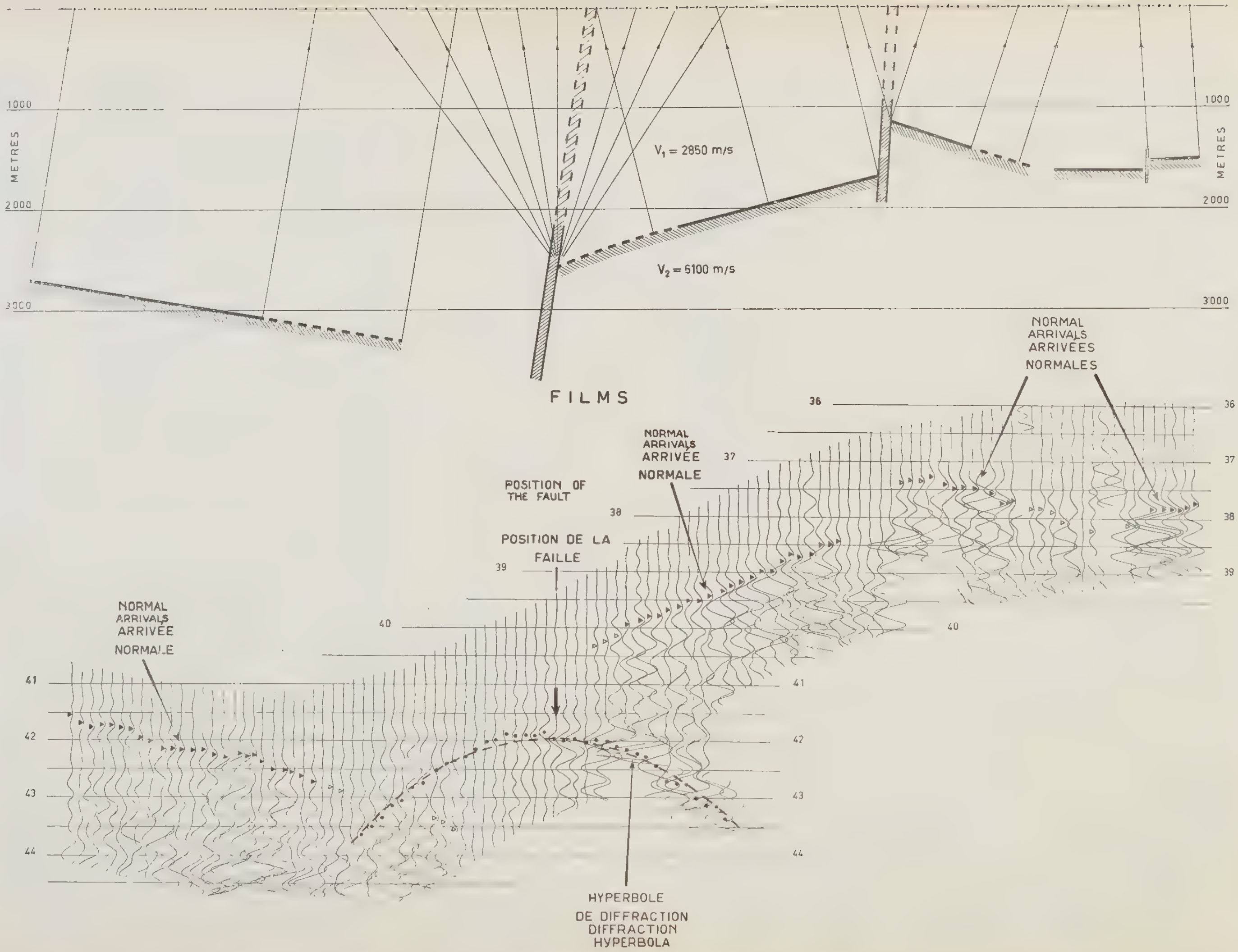

Fig. 6. Essai d'interprétation d'un phénomène de diffraction au passage d'une faille; tir en arc.
Tentative interpretation of a diffraction phenomenon at a fault; arc shooting

ou plutôt du double offset par corrélation à vue entre deux irrégularités de même forme attribuées au marqueur (Fig. 7, 1°). Quoique théoriquement valable, ce procédé est souvent d'une application délicate: il peut être difficile dans certains cas de faire la part, dans un ensemble complexe d'irrégularités, de ce qui revient au marqueur, et les risques d'erreur sont importants.

L'utilisation des figures de diffraction, si elle reste limitée au cas où de tels phénomènes apparaissent effectivement, ne présente pas de risques d'erreur de même nature. Cette méthode se rapproche beaucoup, dans son principe, de la détermination des vitesses en sismique-réflexion par la courbure des indicatrices, soit sous la forme habituelle, soit à l'aide des abaques de HAGEDOORN (courbure maximum); on pourrait d'ailleurs songer à utiliser ces abaques pour la réfraction: une simple modification d'échelle devrait suffire.

Nous préfèrerons ici traiter directement le problème.

a) *Principe*

Les figures 7 et 8 reprennent les formules précédemment établies et illustrent le processus suivi pour une détermination indépendante des vitesses verticales:

Tir en ligne (Fig. 7, 2°)

1°) — Détermination par la *courbure de l'hyperbole de diffraction* (un exemple en sera indiqué plus loin).

2°) — Détermination par l'offset, égal à la distance horizontale entre l'axe de l'hyperbole et le point de contact hyperbole — dromochronique (compartiment „up''). Il faut évidemment tenir compte du pendage du marqueur dans ce compartiment.

Tir en arc (Fig. 8)

— Détermination par la *courbure de l'hyperbole de diffraction* qui permet d'atteindre la quantité $V_1/\cos i$ (voir également l'exemple ci-dessous).

L'observation d'une hyperbole de diffraction fournit donc *deux* nouvelles déterminations indépendantes de V_1 pour un tir en ligne, une seule pour un tir en arc. La comparaison des valeurs ainsi obtenues avec les valeurs précédemment adoptées confirme ou infirme les hypothèses initiales et peut conduire à une réinterprétation bien meilleure de l'ensemble d'une étude.

b) *Application pratique*

Nous appliquerons ces méthodes aux hyperboles de diffraction des Fig. 4 et 6.

En portant en abscisses les valeurs de X^2, en ordonnées les valeurs de Θ^2, les équations:

$\Theta^2 = \Theta_0^2 + X^2/V_1^2$ pour le tir en ligne

$\Theta^2 = \Theta_0^2 + (X^2 \cos^2 i)/V_1^2$ pour le tir en arc

représentent des droites de pente respective $1/V_1^2$ et $\cos^2 i/V_1^2$

Sur les figures 9 et 10, on peut voir que les points expérimentaux s'alignent effectivement sur des droites correspondant aux vitesses:

$V_1 = 2600$ pour le tir en ligne
$V_1 = 2650$ pour le tir en arc

Or les valeurs de V_1, précédemment déterminées par la méthode classique sur des profils en double contrôle, étaient respectivement de 2600 et 2850 m/s. La concordance entre les deux déterminations est donc satisfaisante.

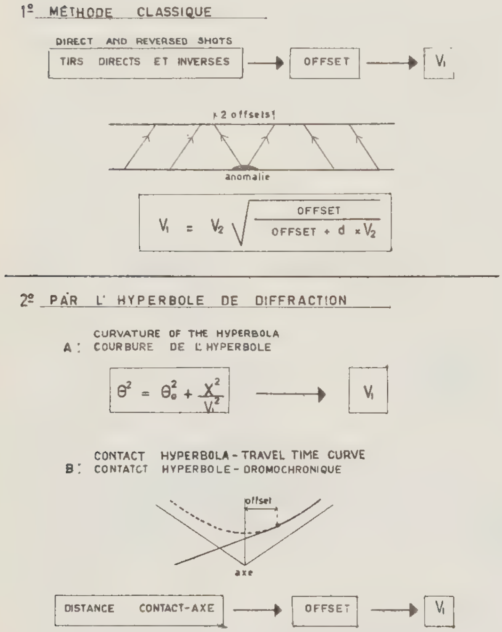
1° MÉTHODE CLASSIQUE
DIRECT AND REVERSED SHOTS
TIRS DIRECTS ET INVERSES
OFFSET
V₁
2 offsets
anomalie
V₁ = V₂ √(OFFSET / (OFFSET + d × V₂))
2° PAR L' HYPERBOLE DE DIFFRACTION
CURVATURE OF THE HYPERBOLA
A : COURBURE DE L' HYPERBOLE
θ² = θ₀² + X²/V₁²
V₁
CONTACT HYPERBOLA - TRAVEL TIME CURVE
B : CONTATCT HYPERBOLE - DROMOCHRONIQUE
offset
axe
DISTANCE CONTACT-AXE
OFFSET
V₁

Fig. 7. Tir en ligne; détermination de V^1.
In line shooting; determination de V^1.

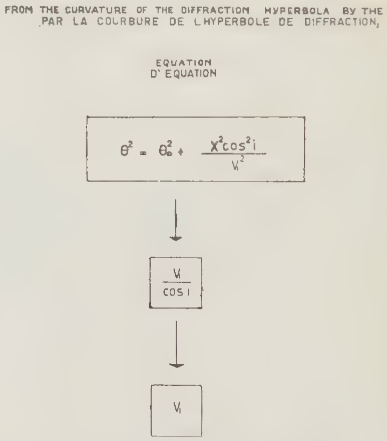
FROM THE CURVATURE OF THE DIFFRACTION HYPERBOLA BY THE
PAR LA COURBURE DE L HYPERBOLE DE DIFFRACTION,
EQUATION
D' EQUATION
θ² = θ₀² + X²cos²i / V₁²
V₁ / cos i
V₁

Fig. 8. Tir en arc; détermination de V^1.
Arc shooting; determination of V^1.

c) *Remarques*

Les hypothèses sur l'homogénéité du terrain de recouvrement ne sont en réalité jamais rigoureusement réalisées. Pour des obliquités faibles des rayons diffractés cependant, l'approximation est bonne. On peut songer à l'améliorer dans le cas d'une loi de vitesses quelconque. Il suffirait de comparer la courbe expérimentale $\Theta = F(X)$ à un réseau de courbes théoriques correspondant à différentes valeurs de V_1 (HAGEDOORN).

Le choix de la quantité Θ_0, dans les calculs précédents, fait intervenir V_1; si la première détermination de V_1 est entachée d'une erreur, trop grande, il convient de reprendre la construction de la droite $\Theta^2 = F(X^2)$ avec la nou-

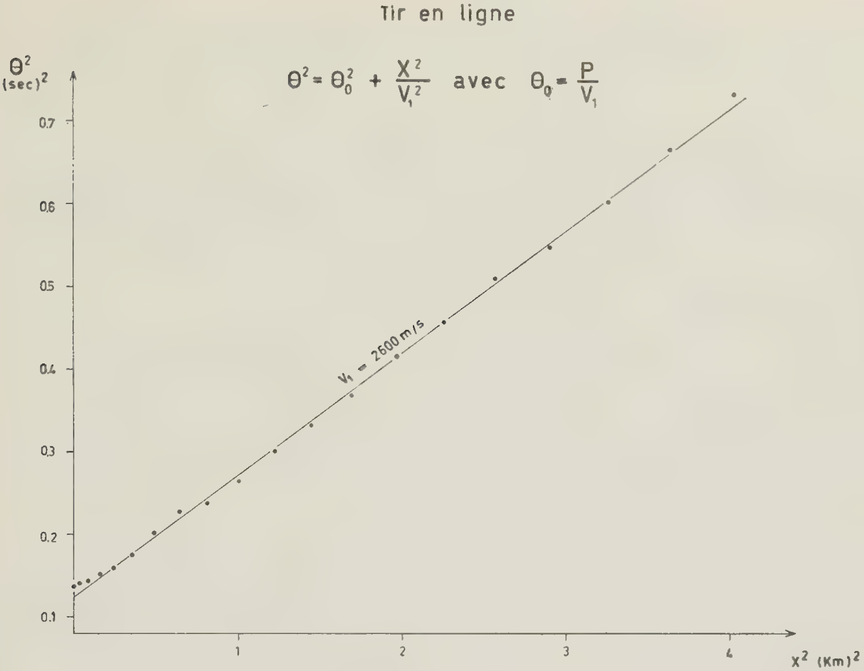

Fig. 9. Courbe $\Theta^2 = f(x^2)$ pour l'hyperbole de diffraction de la Fig. 4; tir en ligne.
Curve $\Theta^2 = f(x^2)$ for the diffraction hyperbola of Fig. 4; in line shooting.

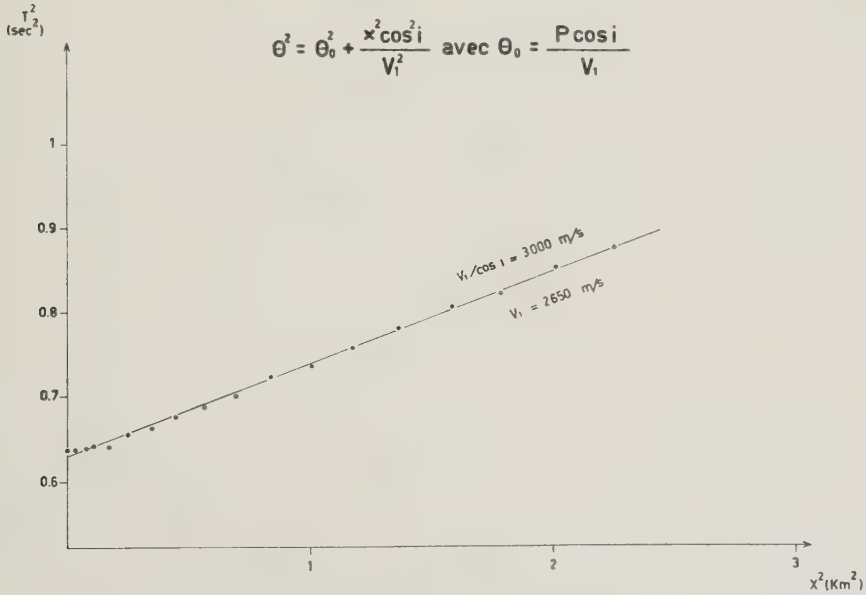

Fig. 10. Courbe $\Theta^2 = f(x^2)$ pour l'hyperbole de diffraction de la Fig. 6; tir en arc.
Curve $\Theta^2 = f(x^2)$ for the diffraction hyperbola of Fig. 6; arc shooting.

velle valeur ; la pente de la nouvelle droite suffira en général à fournir V_1 avec une approximation satisfaisante.

CONCLUSIONS

Les exemples présentés illustrent l'importance de l'information issue de l'étude des phénomènes de diffraction en sismique-réfraction. Nous n'avons voulu présenter qu'un schéma d'interprétation, basé sur des considérations théoriques simples.

Quant aux critères d'apparition des diffractions au passage des failles, ils semblent rattachés à l'existence d'un fort contraste de vitesses entre le marqueur et le recouvrement. Il est toutefois probable que la rareté des observations de ce genre puisse être attribuée aux imperfections de l'enregistrement, qui ne permet pas toujours de suivre assez loin les arrivées tardives.

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ÉTUDE DE L'ATTÉNUATION DE L'INFLUENCE DES ANOMALIES SUPERFICIELLES DANS LE CALCUL DE LA DÉRIVÉE SECONDE DE LA GRAVITÉ *)

PAR

JEAN GOGUEL et JEANNINE LEMOINE

ABSTRACT

In order to eliminate the effect of smoothing due to the use of a finite number of grid points, the second derivative is computed by integrating the product of g with a convenient continuous function, which yields the second derivative to the extent to which the first terms of the Taylor expansion of g represent its value correctly. By applying this method to the anomaly caused by an isolated mass, and to that caused by a homogeneous half plane, it is shown that, if the result obtained is interpreted as if it really were a second derivative, erroneous values for the depth and the mass are obtained. If the real depth of the mass is small, a too large apparent depth is obtained. In the case of a half plane the use of a system of grid points gives the same result. These considerations permit the rational choice of the method of computing the second derivative, such that the effects of too shallow mass irregularities are attenuated.

L'interprétation des prospections gravimétriques a été grandement facilitée par le calcul de fonctions assimilées par le langage courant à la ,,dérivée seconde verticale de la pesanteur''. Cette assimilation appelle cependant des réserves qui apparaissent très nettement lorsque l'on remarque que, si nous disposions d'un instrument capable de mesurer directement cette dérivée seconde, son emploi serait rendu très difficile par l'influence prépondérante de tout ce qui se trouverait au voisinage immédiat de l'appareil; pour fixer les idées, s'il était à 1,50 m du sol, une pierre de 675 grammes posée sur celui-ci produirait le même effet que la structure située à 1.500 m de profondeur et produisant une anomalie de 2 mgal.

Nous nous proposons d'examiner pourquoi les ,,dérivées secondes'' calculées selon les formules usuelles ne souffrent pas de ces défauts. Une première explication vient immédiatement à l'esprit: nos calculs portent, non sur la valeur vraie de g, mais seulement sur les valeurs prises aux sommets d'un quadrillage entre lesquelles on peut considérer que nous avons affaire à une fonction régulière, ne comportant pas les variations rapides dues aux irrégularités superficielles.

L'objet de la présente note est d'analyser un autre phénomène qui, même

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*) Presented at the Twelfth Meeting of the European Association of Exploration Geophysicists, held in Brussels, 5-7 June 1957.

si les valeurs de g étaient continues et n'avaient subi aucun lissage, élimine les irrégularités de la dérivée seconde dues aux masses proches de la surface. Pour le mettre en évidence, nous modifierons le mode de calcul de la dérivée seconde de manière à supprimer l'effet de l'usage des valeurs discontinues. Nous désignerons donc comme ,,résiduelle'' une quantité R définie de la manière suivante, au point x_0, y_0; posant pour abréger $\xi = x - x_0$, $\eta = y - y_0$; nous nous donnerons une fonction f soumise aux conditions suivantes:

$$\iint f(\xi,\eta)\, d\xi\, d\eta = 0 \tag{1}$$

$$\iint \xi f(\xi,\eta)\, d\xi\, d\eta = 0 \tag{2}$$

$$\iint \eta f(\xi,\eta)\, d\xi\, d\eta = 0 \tag{3}$$

$$\iint \xi\eta f(\xi,\eta)\, d\xi\, d\eta = 0 \tag{4}$$

$$\iint (\xi^2 + \eta^2) f(\xi,\eta)\, d\xi,\, d\eta = -4 \tag{5}$$

et nous poserons: $R = \iint g f(\xi,\eta)\, d\xi\, d\eta$ (6)

Les trois conditions (2), (3), (4) sont remplies en particulier si f est symétrique en ξ et η; la condition (5) est nécessaire pour que la résiduelle R, dans la mesure où g peut être considéré comme représenté d'une manière satisfaisante par les termes des 3 premiers degrés d'un développement de Taylor dans le domaine qui contribue d'une manière significative à l'intégrale (6), se trouve coïncider avec la dérivée seconde verticale. Même lorsqu'on est amené à utiliser une résiduelle telle que R indépendamment de son assimilation à la dérivée seconde, une telle condition présente l'intérêt de nous définir l'unité dans laquelle est exprimée la résiduelle, ce qui peut faciliter beaucoup la comparaison de résiduelles correspondant à des formules différentes et qui, si elles étaient fournies par des formules empiriques brutes, pourraient être d'ordres de grandeurs tout à fait différents.

Les formules habituelles utilisant des points canoniques correspondent au cas particulier où la fonction f est nulle en dehors de ceux-ci et présente en leur voisinage sur une étendue ε la valeur η/ε, si η est le coefficient qui leur est affecté. Notons en passant que notre définition englobe également le gradient vertical calculé selon la formule de Baranov.

Confondre comme on le fait d'ordinaire la résiduelle R avec la dérivée seconde, revient à interpréter la carte des valeurs de R comme s'il s'agissait d'une carte des dérivées secondes. Nous allons chercher, sur quelques cas particuliers, l'erreur à laquelle conduit une telle manière de procéder.

Envisageons d'abord le cas d'une masse isolée; nous prendrons une fonction f continue, et la plus simple, vérifiant les conditions posées est $f = \frac{8}{\pi} \frac{1 - 2\rho^2}{(1 + \rho^2)^4}$.
$(\rho^2 = \xi^2 + \eta^2)$

Cette fonction, comme toute autre vérifiant ces conditions, est positive dans une région, et négative en dehors (Figure 1). Le calcul de la résiduelle a été effectué pour une masse isolée située à différentes profondeurs, par une intégration graphique, méthode relativement longue et qui serait évidemment inapplicable dans la pratique. On se rend facilement compte que quelle que soit la profondeur de la masse, le résultat du calcul est positif dans une région centrale et négatif en dehors (exactement comme la dérivée seconde d'une masse isolée) (figure 2). L'interprétation consistera donc à chercher la profondeur et la grandeur de la masse isolée pour laquelle la dérivée seconde se rapprocherait le plus de la résiduelle calculée. Le plus simple pour cela est de tracer en coordonnées bilogarithmiques la partie positive de la courbe *R* calculée, et la partie positive du profil de la dérivée seconde et d'amener par

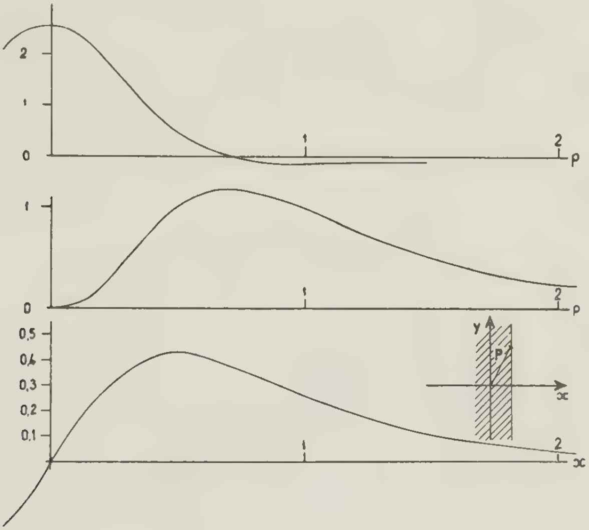

Fig. 1. Courbe représentative de la fonction f choisie, $f = \frac{8}{\pi} \times \frac{1-2\rho^2}{(1+\rho^2)^4}$

de son intégrale jusqu'au rayon ρ, $\int_0^{2\pi}\int_0^{\rho} f\,\rho\,d\rho\,d\theta = \frac{8\rho^2}{(1+\rho^2)^3}$ et de son intégrale jusqu'à une abcisse x, $\int_{-\infty}^{+\infty}\int_{-\infty}^{x} f\,dy\,dx = \frac{3}{2}\,\frac{x}{(1+x^2)^{5/2}}$.

Curve representing the chosen function f, $f = \frac{8}{\pi} \times \frac{1-2\rho^2}{(1+\rho^2)^4}$

its integral up to the radius ρ, $\int_0^{2\pi}\int_0^{\rho} f\,\rho\,d\rho\,d\theta = \frac{8\rho^2}{(1+\rho^2)^3}$ and its integral up to an abscisse x, $\int_{-\infty}^{+\infty}\int_{-\infty}^{x} f\,dy\,dx = \frac{3}{2}\,\frac{x}{(1+x^2)^{5/2}}$.

une double translation ces deux courbes à se rapprocher le plus possible. La démonstration classique relative au calcul de la dérivée seconde montre que, pour une masse profonde, l'interprétation doit donner un résultat correct et

nous nous sommes donc bornés au cas des masses peu profondes; la figure 3 indique, par rapport aux valeurs vraies de *h*, les valeurs trouvées pour la

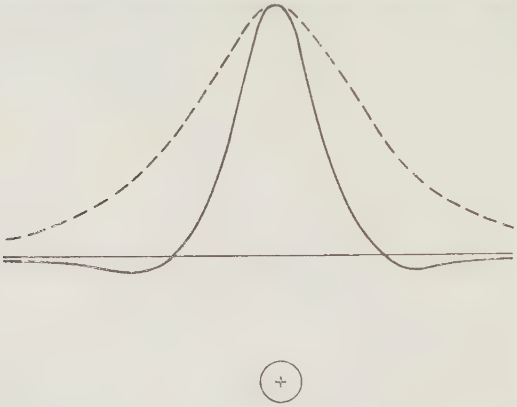

Fig. 2. Profil de la gravité (trait interrompu) et de la dérivée seconde verticale (trait continu) pour une masse isolée.

Profile of the gravity (dashed line) and of the vertical second derivative (continuous line) for an isolated mass.

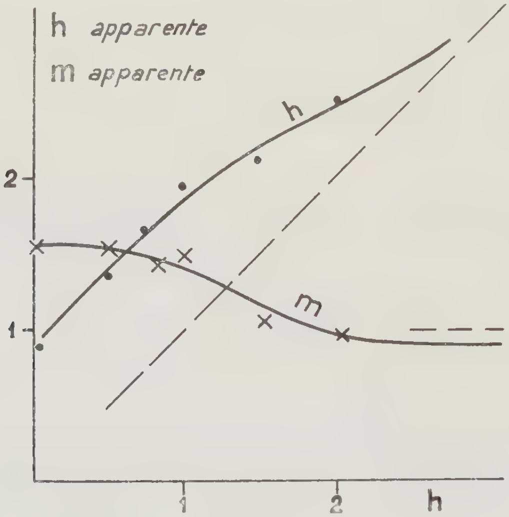

Fig. 3. Résultat de l'interprétation de la dérivée seconde calculée à l'aide de la fonction *f* continue, en fonction de la profondeur de la masse.

Result of the interpretation of the second derivative calculated with the help of the continuous function *f*, as a function of the depth of the mass.

masse et la profondeur apparentes. On voit que celle-ci, pour une masse superficielle, tend vers une limite qui est de 0,866 et que la masse interprétée atteint progressivement 1,50 fois la masse vraie. Tout se passe donc comme si les anomalies de densité voisines de la surface se trouvaient repoussées à une certaine profondeur, supérieure de près d'une unité à leur profondeur réelle, leur grandeur étant par ailleurs multipliée par un coefficient peu différent de l'unité. On s'explique ainsi que les masses très superficielles n'aient sur la résiduelle qu'un effet beaucoup plus faible que sur la dérivée seconde.

Un calcul analogue peut être refait pour un demi plan de densité uniforme situé à une profondeur déterminée, et ceci aussi bien avec une fonction f continue qu'avec les points canoniques d'usage habituel. On profite, dans le premier cas de la relation:

$$\int_{-\infty}^{+\infty} \int_{-\infty}^{x} f \, d\eta \, d\xi = \frac{3}{2} \frac{x}{(1 + x^2)^{5/2}}$$

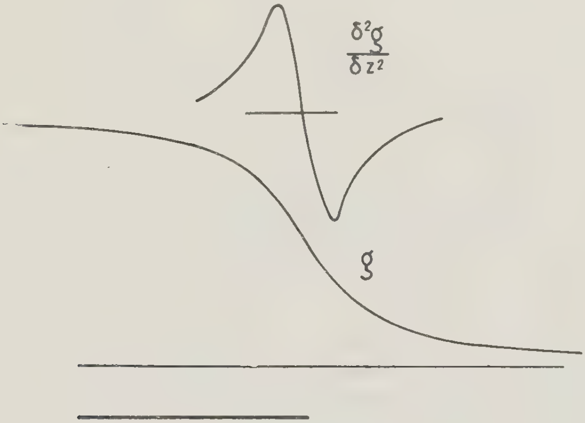

Fig. 4. Profil de la gravité et de la dérivée seconde pour un demi-plan homogène.
Profile of the gravity and of the second derivative for a homogeneous half plane.

La figure 5 indique les profils de R calculés pour différentes profondeurs et la figure 6 montre que les densités et les profondeurs apparentes fournies par l'interprétation de R comme s'il s'agissait d'une dérivée seconde présentent exactement la même allure que pour la masse isolée.

Pour le demi plan le calcul peut être refait avec des points canoniques, et nous avons utilisé la formule d'Elkins:

$$\left(\frac{\delta^2 g}{\delta z^2}\right)_P = \frac{1}{24 s^2} \left[96 \, g_P - 18 \, \Sigma g(s) - 8 \, \Sigma g(s\sqrt{2}) + \Sigma g(s\sqrt{5})\right] \text{ avec } s = 1$$

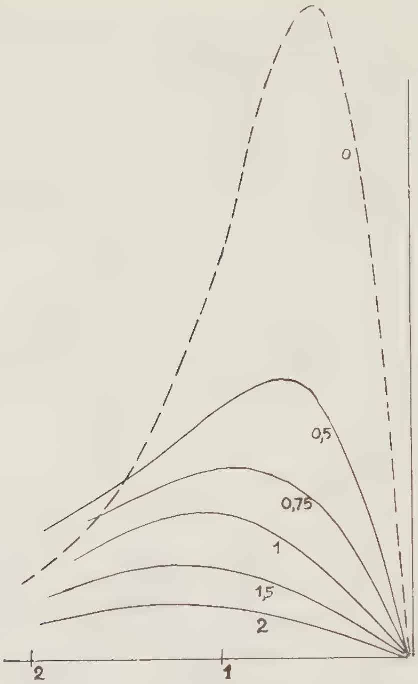

Fig. 5. Profils de la dérivée seconde calculée à l'aide de la fonction *f* continue pour diverses profondeurs.

Profiles of the second derivative calculated with the help of the continuous function *f* for various depths.

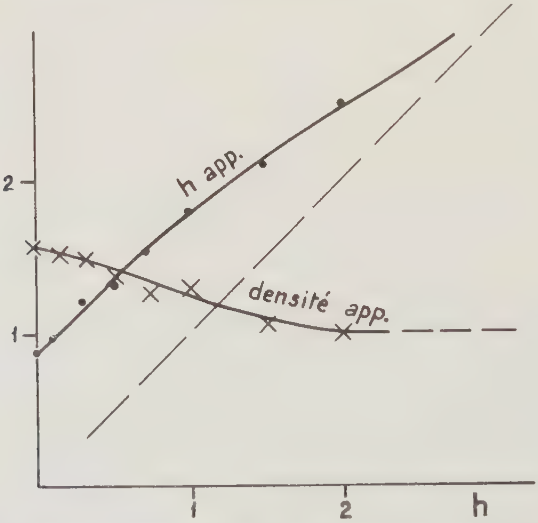

Fig. 6. Résultat de l'interprétation du calcul de la dérivée seconde à l'aide de la fonction *f* continue pour un demi-plan homogène, en fonction de sa profondeur.

Result of the interpretation of the calculation of the second derivative with the continuous function *f* for a homogeneous half plane, as a function of its depth.

Il faut d'ailleurs étudier séparément les cas correspondant à différents azimuths du bord du plan. La figure 7 donne les profils de R calculés pour un azimuth de 30 degrés pour différentes profondeurs, et la figure 8 donne ces mêmes profils en coordonnées bilogarithmiques, ainsi que la courbe théorique pour le demi plan qui doit être amenée en coïncidence approchée avec eux pour interpréter la profondeur et la densité. La figure 9 donne les résultats de cette interprétation et montre que, comme précédemment, la profondeur apparente est, pour les faibles profondeurs trop fortes d'environ une unité et que la densité apparente augmente et approche du double de la densité vraie. D'autres orientations du bord du demi plan donnent d'ailleurs des résultats assez sensiblement différents: figures 10 et 11.

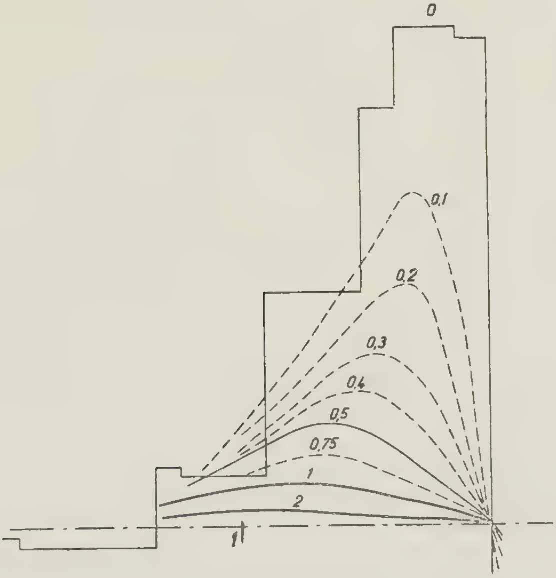

Fig. 7. Calcul de la dérivée seconde par la formule d'Elkins pour un demi-plan d'azimuth 30°, à diverses profondeurs.

Calculation of the second derivative by means of the Elkins' formula for a half plane of an azimutb of 30°, at various depths.

Cette influence de l'azimuth n'est importante que parce que nous étudions une masse fictive, de forme géométrique, qui peut prendre des positions particulières par rapport aux directions du quadrillage. Dans la réalité, les formes des corps géologiques sont beaucoup moins régulières, et il n'y aurait rien à craindre d'analogue à cette influence de l'azimuth. Nous pouvons donc retenir que lorsque le caractère discontinu et l'orientation particulière du réseau des points canoniques n'introduisent pas de perturbation, les conclusions auxquelles nous avait conduit l'emploi d'une fonction f continue subsistent

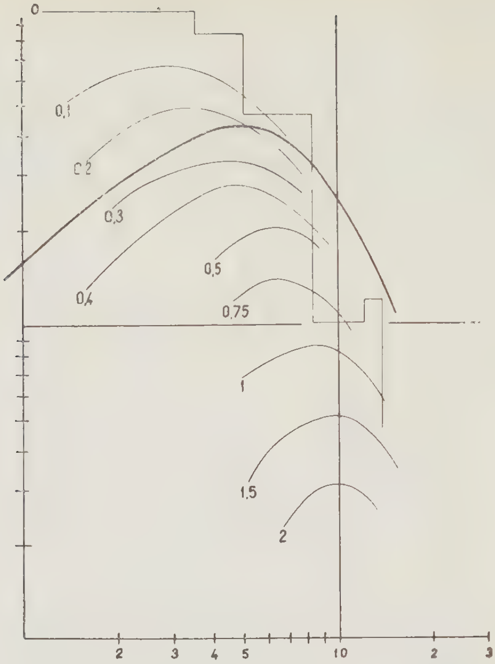

Fig. 8. Profils de la dérivée seconde calculés par la formule d'ELKINS pour un demi-plan d'azimuth 30°, en coordonnées bilogarithmiques, avec, en trait fort, le profil théorique avec lequel il devrait être amené en coïncidence par translation.

Profiles of the second derivative calculated by means of the ELKINS' formula for a half plane of an azimuth of 30°, in logarithmic coordinates with, in heavy line, the theoretical profile with which it should be brought into coincidence by parallel displacement.

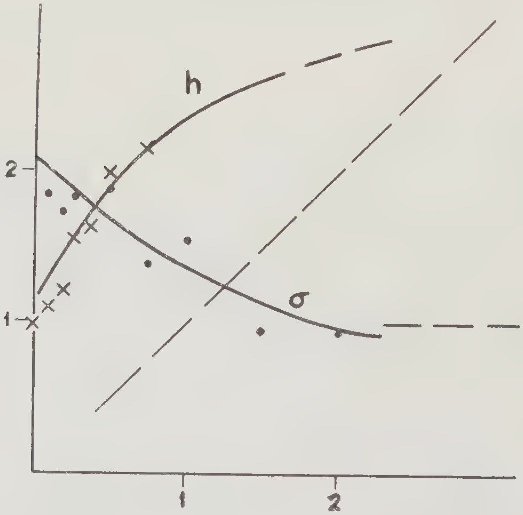

Fig. 9. Résultat de l'interprétation du calcul de la dérivée seconde calculée par la formule d'ELKINS pour un demi-plan d'azimuth 30°, en fonction de la profondeur.

Result of the interpretation of the calculation of the second derivative calculated by means of the ELKINS' formula for a half plane of an azimuth of 30°, as a function of the depth.

et que, lorsque nous interprétons la résiduelle comme une dérivée seconde, cela revient à repousser au delà d'une certaine profondeur limite les masses voisines de la surface, en les multipliant par un coefficient peu différent de l'unité.

Un calcul analogue pourrait facilement être refait pour les nombreuses

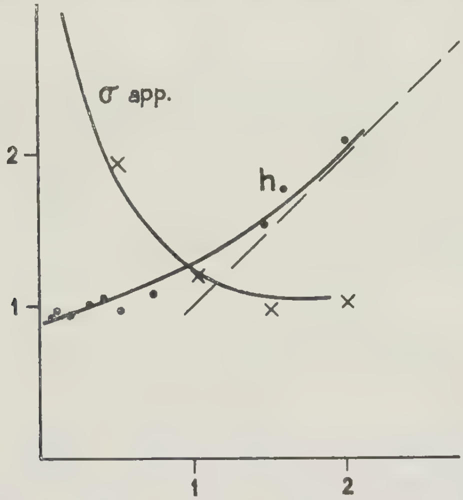

Fig. 10. Résultat de l'interprétation de la dérivée seconde calculée par la formule d'Elkins pour un demi-plan d'azimuth 0°, en fonction de la profondeur.

Result of the interpretation of the second derivative calculated by means of the Elkins' formula for a half plane of an azimuth of 0° as a function of the depth.

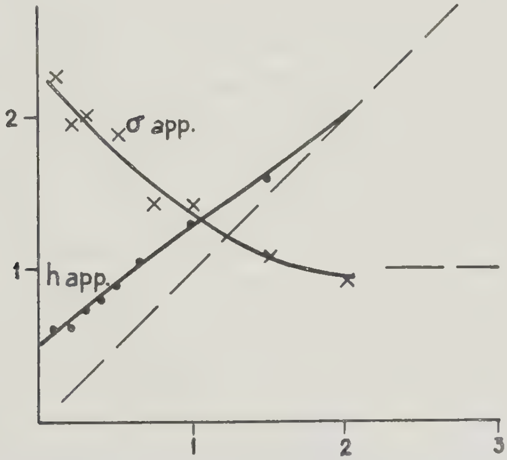

Fig. 11. Résultat de l'interprétation de la dérivée seconde calculée par la formule d'Elkins pour un demi-plan d'azimuth 45°, en fonction de la profondeur.

Result of the interpretation of the second derivative calculated by means of the Elkins' formula for a half plane of an azimuth of 45° as a function of the depth.

autres formules qui ont été proposées pour le calcul de la ,,dérivée seconde''. Il indiquerait, en fonction du pas, qui a été pris ici pour unité, la profondeur à laquelle se trouvent fictivement repoussées les masses proches de la surface, lorsque la résiduelle est interprétée comme si il s'agissait d'une véritable dérivée seconde. Cette profondeur est évidement liée à la distance à laquelle changent les coefficients appliqués aux points canoniques, mais ne lui est pas simplement proportionnelle.

Ce critère parait important à retenir pour choisir le mode de calcul d'une résiduelle pour une prospection déterminée; on sait en effet, a priori, la profondeur à laquelle ont des chances de se trouver les structures qui nous intéressent, et il convient donc de choisir une formule et un pas tels que la majoration fictive de profondeur, dans l'interprétation de la résiduelle comme une dérivée seconde, soit relativement faible pour cette profondeur, et qu'au contraire, elle soit relativement forte pour les profondeurs moindres, où des anomalies ne présenteraient pas d'intéret pratique, afin d'atténuer leur influence. Des diagrammes tels que ceux des figures 6, 9, 10 et 11 permettent d'effectuer en connaissance de cause le choix du pas, en fonction des profondeurs intéressantes.

Mais d'autres critères sont à prendre aussi en considération. Pour utiliser toutes les finesses des mesures, il faut évidement faire intervenir dans le calcul les valeurs interpollées aux sommets d'un réseau, qu'il soit triangulaire ou carré, dont le coté ne soit pas trop supérieur à l'intervalle entre stations. Si ceci conduisait à un pas nettement plus faible que celui indiqué par la considération de la profondeur des anomalies à mettre en évidence, on aurait le choix, soit de prendre une autre formule, soit d'appliquer la formule à un pas multiple de celui du réseau des valeurs canoniques.

Nous pensons cependant qu'il ne faut pas abuser de cette dernière solution, et ne l'adopter qu'avec une formule faisant intervenir un assez grand nombre de points, faute de quoi une anomalie très localisée de g pourrait donner lieu à des variations périodiques de la résiduelle. L'emploi des machines électroniques permet d'ailleurs sans difficulté l'usage de formules comportant un nombre relativement élevé de points canoniques.

Au contraire, si les stations de mesures sont relativement espacées, et conduisent à adopter pour le pas du réseau canonique une longueur un peu forte, par rapport à la profondeur des structures cherchées, on sera conduit à faire appel à une formule relativement simple, où le changement de signe des coefficients appliqués aux points canoniques a lieu assez près du centre.

Il est bien évident qu'aucun artifice de calcul ne peut tirer de mesures en des stations trop espacées un détail qu'elles ne comportent pas. Mais inversement, il faut éviter que l'effet de lissage des données expérimentales que peut entrainer l'emploi d'une formule de calcul de résiduelle ne fasse disparaitre des éléments utiles d'information. Nous avons cherché à caractériser l'atténuation de l'effet des masses superficielles, qui correspond à ce lissage, dans le but de permettre un choix rationnel du mode de calcul de la résiduelle le mieux adapté à chaque problème de prospection.

DISCUSSION

V. Baranov (written discussion):

On sait que, quand on calcule une "seconde dérivée" par une formule approchée utilisant les valeurs discrètes de la gravité, c'est-à-dire ses valeurs en un certain nombre de points isolés formant une grille, cette dernière a les propriétés d'un filtre: comme une sorte de tamis, elle ne retient que des anomalies d'une certaine étendue. Des anomalies localisées dont l'étendue est inférieure au pas de la grille ,,passent à travers les mailles" sans affecter sensiblement la valeur calculée de la seconde dérivée.

M. Goguel souligne que ce n'est pas seulement l'emploi de valeurs en des points isolés — avec l'hypothèse d'une variation régulière de la gravité entre ces points — qui provoque cet effet de filtrage, mais aussi le fait même de se servir de la formule approchée. Ainsi, même si l'on admet que les valeurs de la gravité sont connues en tout point et avec toute la précision possible, et même si l'on fait le calcul par une formule utilisant, théoriquement, toutes les valeurs, on obtiendra encore un effet de filtre — à condition d'employer une formule approchée. La conclusion de l'étude de Monsieur Goguel peut être formulée ainsi:

quelle que soit la façon d'approcher la vraie valeur de la seconde dérivée, l'approximation agit toujours dans le même sens, à savoir, en diluant les anomalies de faible étendue.

Il faut cependant noter que les deux causes indiquées par M. Goguel n'agissent pas simultanément. En effet, examinons d'abord le procédé classique basé sur l'emploi des points canoniques isolés. La dérivée seconde par rapport à z est définie localement; changée de signe, elle est égale à la somme des secondes dérivées par rapport à x et à y. Or, la définition de la deuxième dérivée est:

$$\delta g^2/\delta x^2 = \lim_{a=0} \frac{g(x—a) — 2g(x) + g(x+a)}{a^2}$$

Pratiquement, nous ne pouvons pas faire tendre a vers zéro. La valeur minimale de a est le pas de la grille. La valeur exacte de g'' se trouve remplacée par une valeur moyenne relative à une aire non nulle. Si l'on tente de diminuer a, on est vite arrêté, car l'influence des erreurs expérimentales croît alors démesurément; on arrive à une expression indéterminée de forme O/O. Il est clair que, dans ce cas, des anomalies étroites passent à travers les mailles en raison de l'échantillonnage discontinu du champ.

Examinons maintenant un peu plus en détail, et en nous plaçant à un point de vue plus général, le procédé continu de M. Goguel. Est-il possible de représenter la seconde dérivée par une intégrale

$$R = \frac{\delta^2 g}{\delta z^2} = \int\int g\,(\xi,\eta)\,f\,(\xi,\eta)\,d\xi\,d\eta$$

ou, en coordonnées polaires

$$R = \int\int g\,(\rho,\omega)\,f\,(\rho,\omega)\,\rho\,d\rho\,d\omega$$

Ici la fonction $\rho f(\rho,\omega)$ peut etre considérée comme un poids par lequel il faut multiplier la valeur mesurée de g. Or, il est clair que ce poids doit être le même quel que soit l'azimut. Ceci nous conduit à ne considérer que les fonctions f ne dépendant pas de ω. Alors, en posant, comme d'habitude

$$\bar{g}(\rho) = \frac{1}{2\pi}\int_0^{2\pi} g\,(\rho,\,\omega)\,d\omega$$

on obtient

$$R = 2\,\pi \int_0^{\infty} \bar{g}\,(\rho)\,f(\rho)\,\rho\,d\rho$$

Pour des raisons de commodité, nous poserons:

$$2\,\pi\rho\,f(\rho) = \varphi'''(\rho)$$

Alors

$$R = \int_0^{\infty} \bar{g}(\rho)\,\varphi'''\,(\rho)\,d\rho$$

On sait que la moyenne $\bar{g}$ admet le développement

$$\bar{g}(\rho) = g_0 - \frac{1}{4}\cdot\frac{d^2 g}{dz^2}\rho^2 + C\rho^4 + \ldots\ldots$$

valable d'ailleurs uniquement au voisinage de l'origine et dans le cas où g est analytique. On en tire

$$\frac{d^2 g}{dz^2} = -\,2\,g''\,(0)$$

Par conséquent, si nous voulons que R soit la dérivée seconde, il faut opérer l'identification

$$-2\bar{g}''(0) = \int_0^\infty \bar{g}(\rho)\,\varphi'''(\rho)\,d\rho$$

En toute rigueur c'est évidemment impossible, car le poids φ''' n'est pas une fonction, mais une distribution (au sens de L. Schwarz). On peut toutefois chercher une fonction continue φ si nous consentons à commettre une erreur E. Nous écrirons donc

$$-2\bar{g}''(0) = \int_0^\infty \bar{g}(\rho)\,\varphi'''(\rho)\,d\rho + E$$

En intégrant trois fois par parties, on obtient

$$-2\bar{g}''(0) = -\bar{g}(0)\,\varphi''(0) - \bar{g}''(0)\,\varphi(0) + $$

$$+ E - \int_0^\infty \bar{g}'''(\rho)\,\varphi(\rho)\,d\rho$$

Bien entendu, nous avons posé $\varphi(\infty) = 0$ car le poids diminue rapidement avec $1/\rho$. D'autre part, $\bar{g}'(0) = 0$, la fonction $\bar{g}$ étant paire.

Finalement, l'identification conduit à formuler deux conditions suivantes:

$$\varphi(0) = 2 \qquad\qquad \varphi''(0) = 0$$

Si nous posons avec M. Goguel

$$\frac{d^2g}{dz^2} = \int_0^\infty \bar{g}(\rho)\,\varphi'''(\rho)\,d\rho$$

l'erreur commise sera exprimée par l'intégrale

$$E = \int_0^\infty \bar{g}'''(\rho)\,\varphi(\rho)\,d\rho$$

Il est facile de voir que cette erreur agit dans le même sens que l'échantillonnage discontinu. Considérons, par exemple, une masse ponctuelle m placée sur Oz à une profondeur h. On a

$$g = mk/h^2,\ d^2 g/dz^2 = 6\,mk/h^4$$

$$g'''(\rho) = \frac{mk}{h^5}\left(-9 + 90\,\frac{\rho^2}{h^2} - 105 \cdot \frac{\rho^4}{h^4}\right)$$

Le maximum de $\bar{g}'''(\rho)$ est $9mk/h^5$. Par conséquent, l'erreur commise est de l'ordre de

$$E \leqslant \frac{9\,mk}{h^5} \int_0^\infty |\varphi(\rho)|\, d\rho$$

Elle décroît comme la cinquième puissance de h, tandis que g'' est inversement proportionnelle à h^4. L'erreur relative décroît avec $1/h$. Nous n'insistons pas davantage sur ces considérations théoriques.

J'ajouterai cependant une remarque concernant la première dérivée ou le gradient vertical dg/dz. Contrairement à la seconde dérivée, le gradient vertical est défini par une intégrale

$$\left(-\frac{dg}{dz}\right)_0 = \int_0^\infty \frac{g_0 - \bar{g}(\rho)}{\rho^2}\, d\rho$$

et ceci d'une façon exacte sans aucune erreur.

J. Goguel:

Les remarques de M. Baranov précisent d'une manière très intéressante les raisons mathématiques du phénomène que nous avons analysé plus empiriquement, et je me félicite de les avoir provoquées.

J'en retiendrai surtout que, quelle que soit la fonction $\varphi'''(\rho)$ choisie, l'erreur relative peut devenir très grande pour une valeur suffisament faible de la profondeur h d'une masse isolée; ceci rejoint exactement notre conclusion; mais, réduisant évidement la généralité du raisonnement, nous avons cherché à montrer de plus le sens de l'erreur commise, et son influence sur l'interprétation, pour une des fonctions $\varphi'''(\rho)$ les plus simples auxquelles on puisse songer. Il est d'ailleurs très vraisemblable que l'erreur serait de même sens pour toute autre formule.

SUR L'INTERPRÉTATION DES ANOMALIES GRAVIMÉTRIQUES ET MAGNÉTIQUES *)

(gradient vertical de *g*, magnétisme à terre, aéromagnétisme)

PAR

JÉRÔME CHASTENET DE GERY** ET HENRI NAUDY**

ABSTRACT

For the interpretation of gravimetric and magnetic maps two types of master curves are proposed: firstly those which apply both to the vertical gradient of *g* and to the pseudo gravimetric gradient obtained by reduction to the pole of magnetic maps; and secondly those which apply direct to magnetic anomalies.

With regard to the first type of master curve, the principle and the advantages of the reduction to the pole are discussed. In the last part of the paper it is shown how a set of master curves, calculated for two-dimensional east-west striking structures, can also be used for the interpretation of two-dimensional structures of arbitrary direction of strike. Practical examples of application are given.

RESUME

Pour effectuer l'interprétation, deux catégories d'abaques sont proposées:

1°) Ceux qui s'appliquent aussi bien au gradient vertical de *g* qu'au gradient pseudo-gravimétrique obtenu par réduction au pôle des cartes magnétiques.

2°) Ceux qui s'appliquent directement aux anomalies magnétiques.

A propos de la première catégorie d'abaques, on indique le principe et les avantages de la réduction au pôle. Dans la dernière partie, on montre comment un jeu d'abaques magnétiques calculés pour les anomalies cylindriques orientées est-ouest peut servir à l'interprétation d'anomalies cylindriques de direction quelconque. Des exemples pratiques d'application sont donnés.

Il faut d'abord rappeler, bien que ce soit un lieu commun, que l'interprétation des anomalies gravimétriques et magnétiques est un problème théoriquement indéterminé; pour aboutir à une solution concrète, on doit poser au départ un certain nombre d'hypothèses. On s'inspire pour cela des données géologiques, mais on adopte presque toujours des hypothèses plus simples que la réalité. Aussi ne doit-on pas s'attendre à obtenir des résultats d'une grande précision.

Toutes les méthodes d'interprétation sont d'ailleurs sujettes à cette restriction. Le caractère essentiel qui les distingue réside dans la manière de comparer les anomalies expérimentales aux anomalies théoriques résultant des hypothèses. On effectue souvent sur les anomalies des constructions géométriques à partir desquelles on mesure certaines longueurs (W.B. Agocs and K. Isaacs, 1956, L. J. Peters, 1949, V. Vacquier e.a., 1951). Ces procédés sont rapides, mais plutôt sommaires et il est préférable de comparer l'anomalie expérimentale et l'anomalie théorique dans leur ensemble, c'est-à-dire par superposition directe de deux courbes.

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*) Presented at the Twelfth Meeting of the European Association of Exploration Geophysicists, held in Brussels, 5-7 June 1957.

**) Compagnie Générale de Géophysique, Paris.

Nous allons montrer sur des exemples que la représentation bilogarithmique permet d'y parvenir facilement.

I — Interprétation gravimétrique

Nous commencerons par la gravimétrie, ou plus exactement par le gradient vertical de g. Notre méthode peut aussi s'appliquer à l'anomalie de Bouguer et à sa dérivée seconde, mais la dérivée première est mieux adaptée à une interprétation quantitative (V. Baranov, 1953).

Supposons qu'une structure donnée soit caractérisée par une profondeur h (par exemple la profondeur de son sommet) et par d'autres longeurs a, b, . . . Dans ces conditions, on sait que la valeur, au point de coordonnées x, y, de l'anomalie du gradient vertical dépend des rapports

$$\frac{x}{h}, \frac{y}{h}, \frac{a}{h}, \frac{b}{h} \ldots\ldots$$

Elle est évidemment proportionnelle au contraste de densité. Par conséquent, elle peut se mettre sous la forme générale suivante:

$$\frac{G}{f\sigma} = F\left(\frac{x}{h}, \frac{y}{h}, \frac{a}{h}, \frac{b}{h}, \ldots\right)$$

Le plus souvent, on envisage des structures simples définies par un seul paramètre de forme: a/h (les structures complexes pouvant éventuellement s'obtenir par composition).

Prenons, par exemple, un compartiment cylindrique à parois verticales et infini vers le bas; l'anomalie correspondant à ce cas simple aura la forme représentée sur la figure 1.

Cette anomalie dépend de trois paramètres: le contraste de densité σ, la profondeur du toit du compartiment h et la largeur 2a. La comparaison directe d'une telle anomalie expérimentale avec les anomalies théoriques du même type exigerait donc la manipulation d'un nombre considérable de ces dernières. Mais en réalité les paramètres interviennent sous une forme particulière; l'équation de la courbe

$$G = 2f\sigma\left(\text{Arctg}\,\frac{x+a}{h} - \text{Arctg}\,\frac{x-a}{h}\right)$$

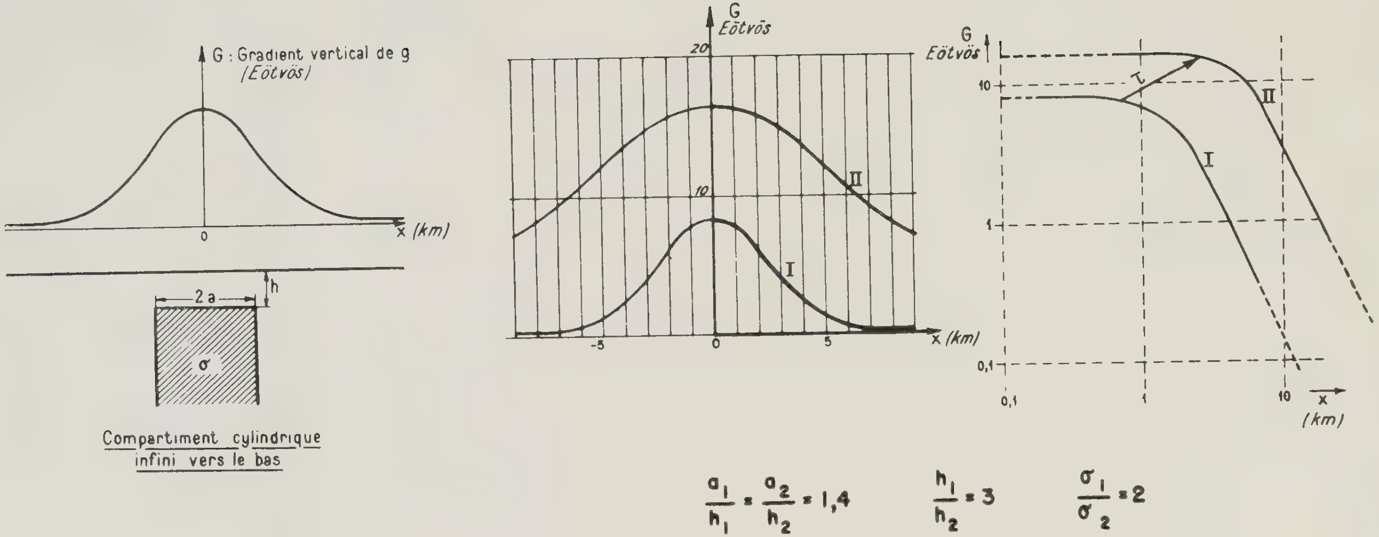


Fig 1 Profils linéaires et bilogarithmiques de compartiments cylindriques infinis vers le bas
Linear and logarithmic profiles of cylindrical compartments extending to infinite depth

peut, en effet, s'écrire sous la forme schématique

$$\frac{G}{f\sigma} = F\left(\frac{x}{h}, \frac{a}{h}\right)$$

où G désigne le gradient vertical de la gravité et F une fonction qui est ici une différence d'Arc tg.

En coordonnées bilogarithmiques, deux courbes de cette famille correspondant à une même valeur de a/h se déduisent l'une de l'autre par une simple translation quelles que soient les valeurs individuelles de a, h et σ. La figure 1 montre deux anomalies correspondant à la même valeur de a/h. On voit à droite la transposition en coordonnées bilogarithmiques du schéma central ou plus exactement de la moitié droite de ce schéma. Alors qu'en coordonnées linéaires la courbe II se déduit de la courbe I par multiplication des abscisses par 3 et multiplication des ordonnées par 2, en coordonnées bilogarithmiques, la courbe II se déduit de la courbe I par la translation définie par le vecteur τ.

Ainsi les paramètres contraste de densité et profondeur n'interviennent plus dans la forme de la courbe, mais seulement dans la translation qu'on doit effectuer pour amener une courbe sur l'autre.

Il suffit donc de construire en coordonnées bilogarithmiques une famille de courbes correspondant à différentes valeurs de a/h pour avoir toutes les formes possibles des anomalies créées par un compartiment cylindrique infini vers le bas. On repère sur ces courbes les lieux des points $x = a$, $x = h$, $G = f\sigma$ (figure 2).

Pour interpréter une anomalie expérimentale, on la transpose sur papier bilogarithmique transparent et on cherche à la faire coïncider avec une des courbes théoriques. Si cette coïncidence est impossible, c'est que l'hypothèse d'un compartiment cylindrique infini vers le bas est incompatible avec l'anomalie à interpréter. Si la coïncidence peut être réalisée d'une manière acceptable, on lit directement sur le graphique de la courbe expérimentale les valeurs de a, h et $f\sigma$.

Les traits pleins de la figure 2 représentent l'abaque proprement dit; les traits tiretés représentent le graphique de la courbe expérimentale qui, dans la pratique, est porté par une feuille transparente que l'on peut déplacer sur l'abaque.

On lit ici $h = 1{,}5$ km, $a = 4{,}6$ km, $f\sigma = 8$ *eötvös* (soit un contraste de densité $\sigma = 8/f = 0{,}12$ car $1/f = 0{,}015$).

Nous avons calculé des abaques pour diverses formes de structures.

D'abord le compartiment de base carrée, infini vers le bas (figure 3). Cet abaque est bien adapté aux structures ayant des sections sensiblement carrées ou circulaires et dont la base inférieure est beaucoup plus profonde que la

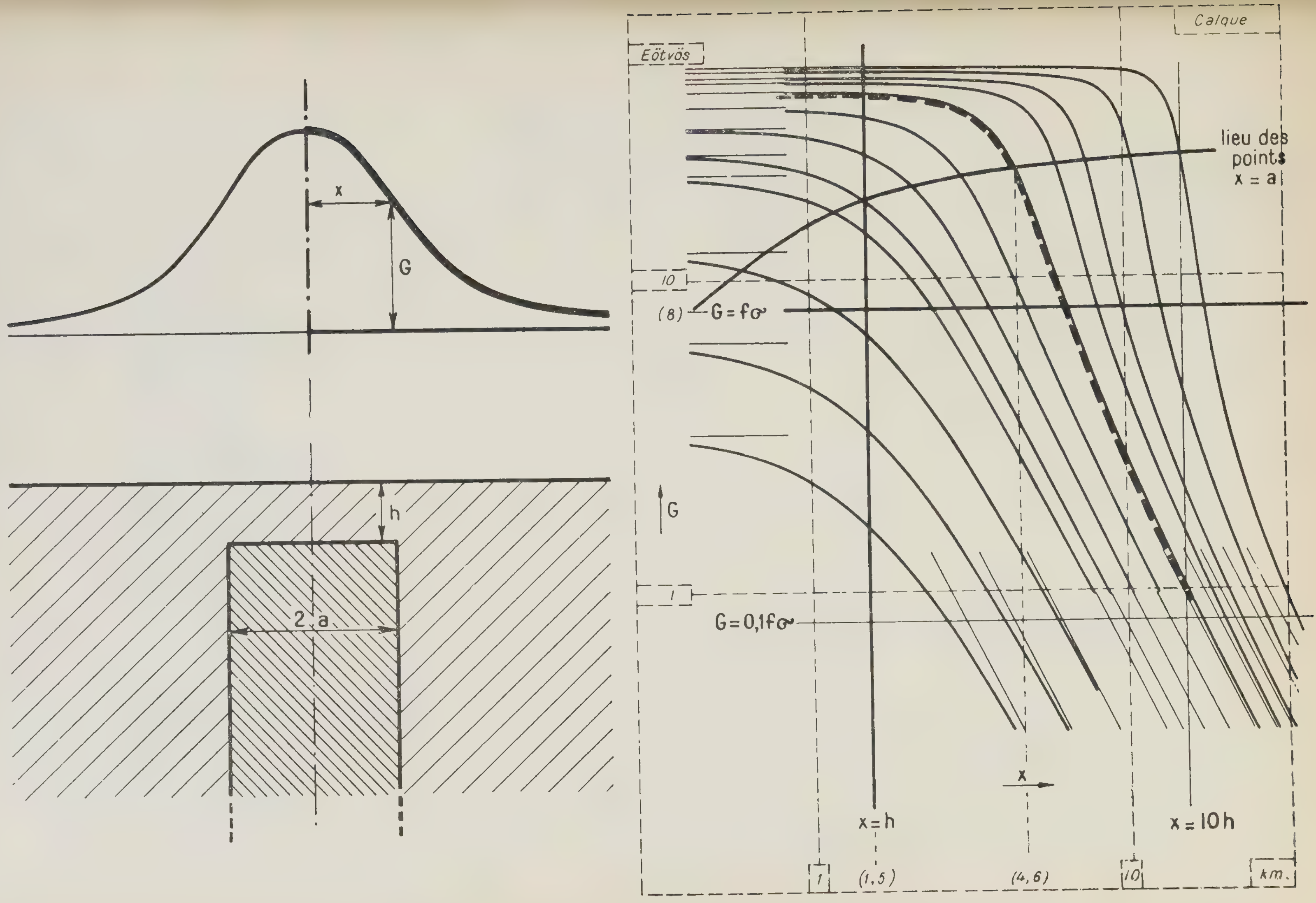
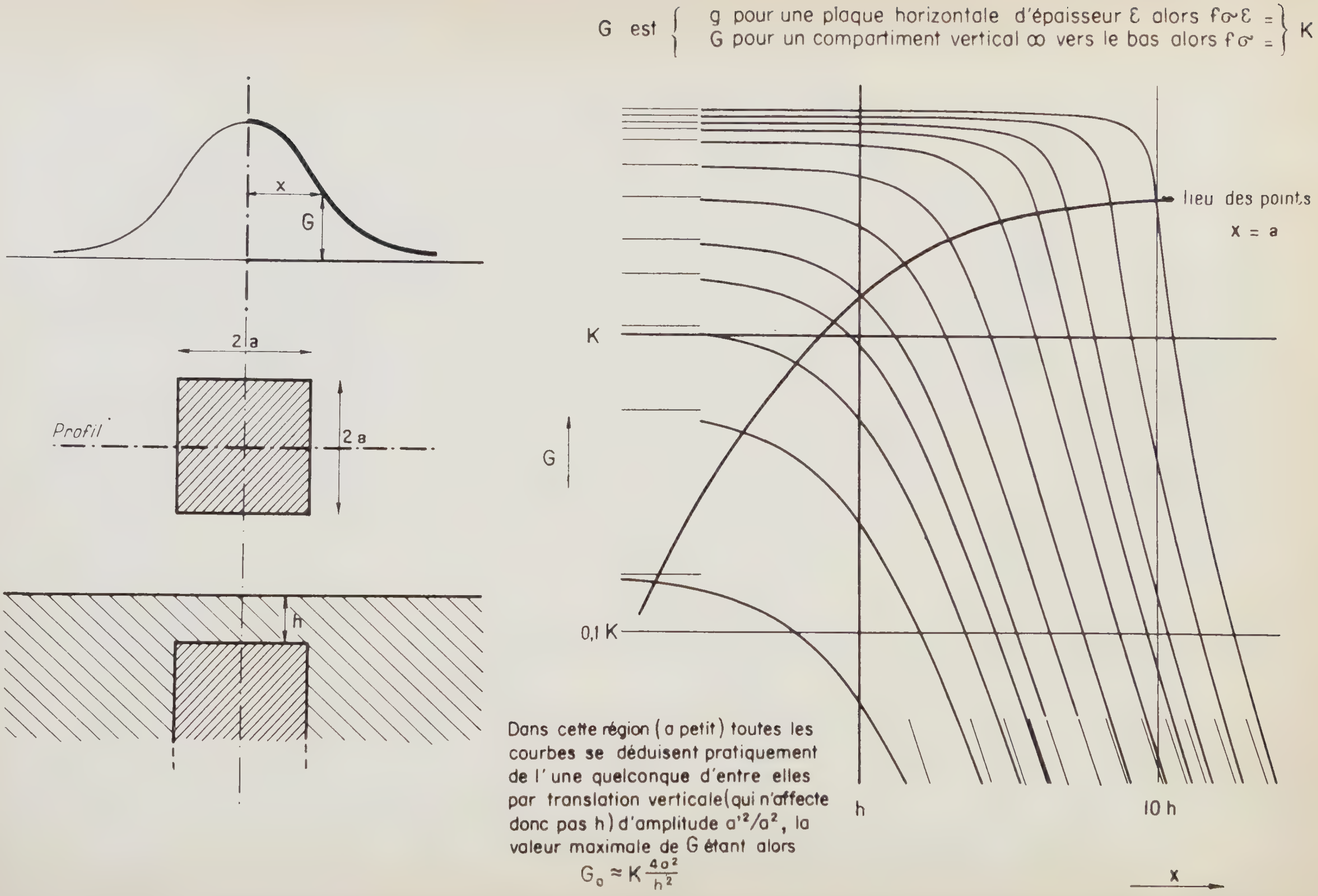


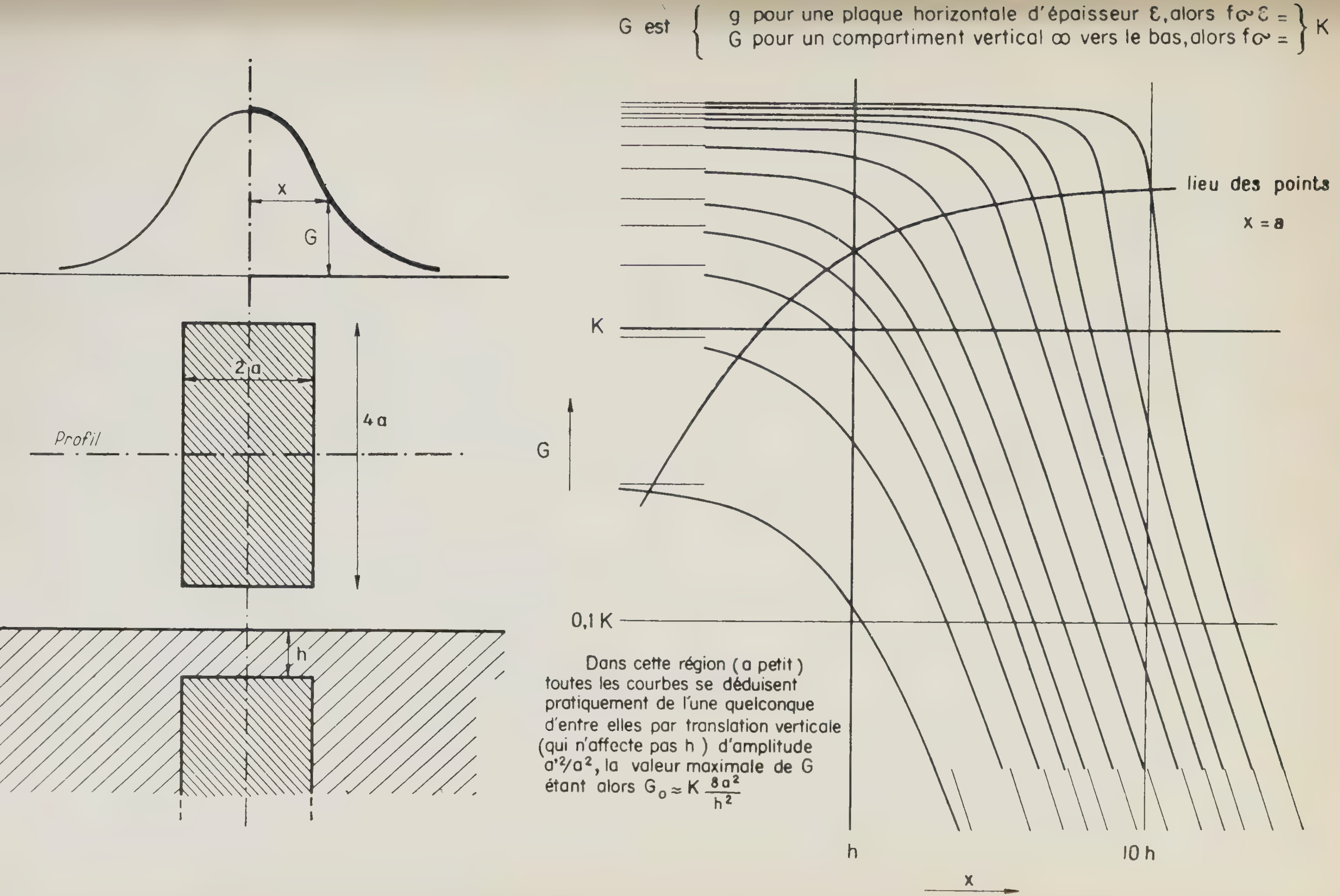
Fig. 2. Profil pangravimétrique $CV \infty T$; compartiment cylindrique infini vers le bas.
Gravity master profile $VC \infty T$; cylindrical compartment extending to infinite depth.



G est { g pour une plaque horizontale d'épaisseur ε alors fσε = ; G pour un compartiment vertical ∞ vers le bas alors fσ = } K

Dans cette région (a petit) toutes les courbes se déduisent pratiquement de l'une quelconque d'entre elles par translation verticale (qui n'affecte donc pas h) d'amplitude a'^2/a^2, la valeur maximale de G étant alors $G_0 \approx K \frac{4a^2}{h^2}$

Fig. 3. Profil pangravimétrique *CV.* 1 *T.* / Gravity master profile *VC.* 1*T.*



G est { g pour une plaque horizontale d'épaisseur ε, alors fσε = } K
G pour un compartiment vertical ∞ vers le bas, alors fσ = } K

Dans cette région (a petit) toutes les courbes se déduisent pratiquement de l'une quelconque d'entre elles par translation verticale (qui n'affecte pas h) d'amplitude a'^2/a^2, la valeur maximale de G étant alors $G_0 \simeq K \frac{8a^2}{h^2}$

Fig. 4. Profil pangravimétrique *CV. 2T.* / Gravity master profile *VC. 2T.*

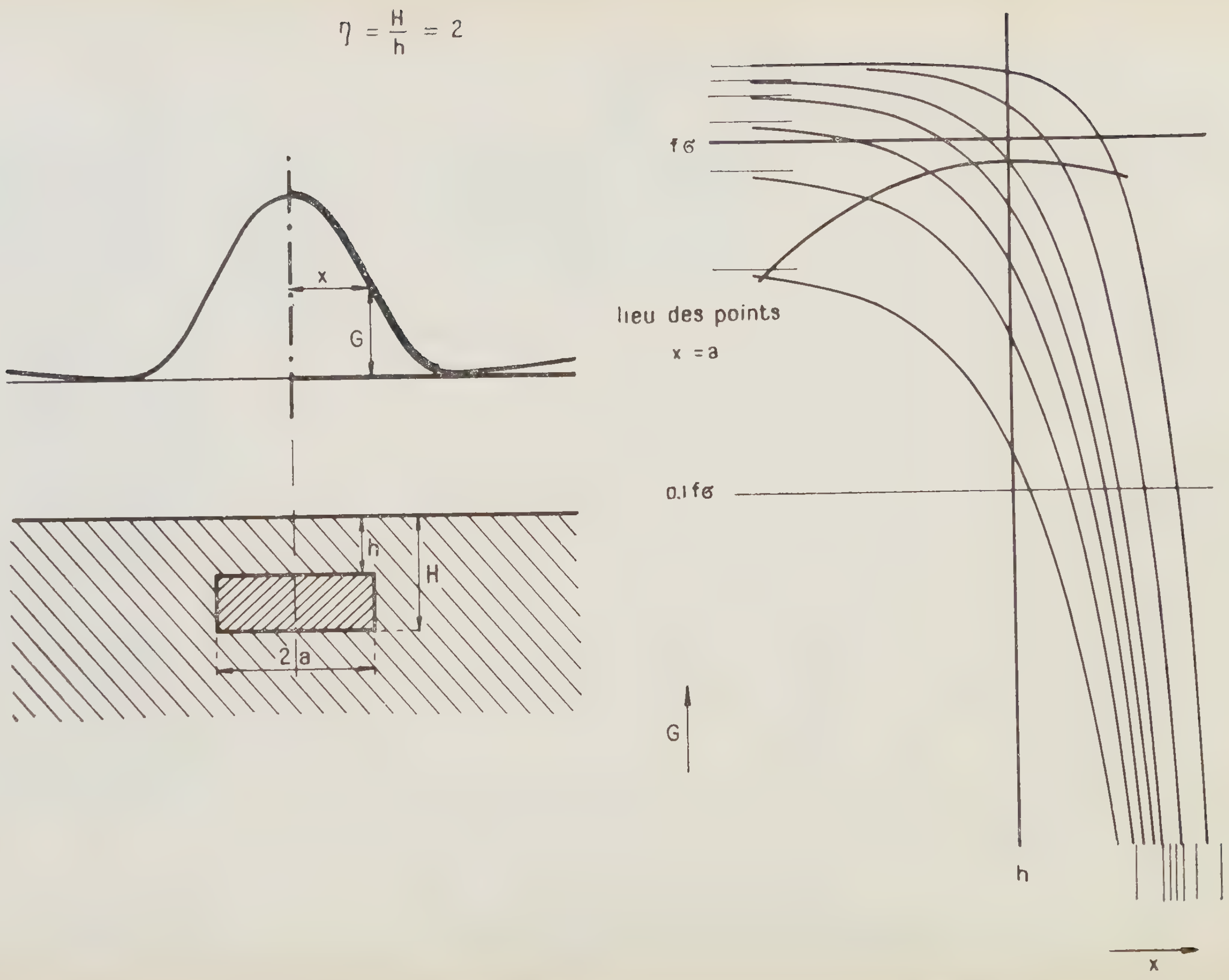


Fig. 5. Profil pangravimétrique *P*2; Compartiment cylindrique limité vers le bas
Gravity master profile *P*2: Cylindrical compartment of limited depth extent.

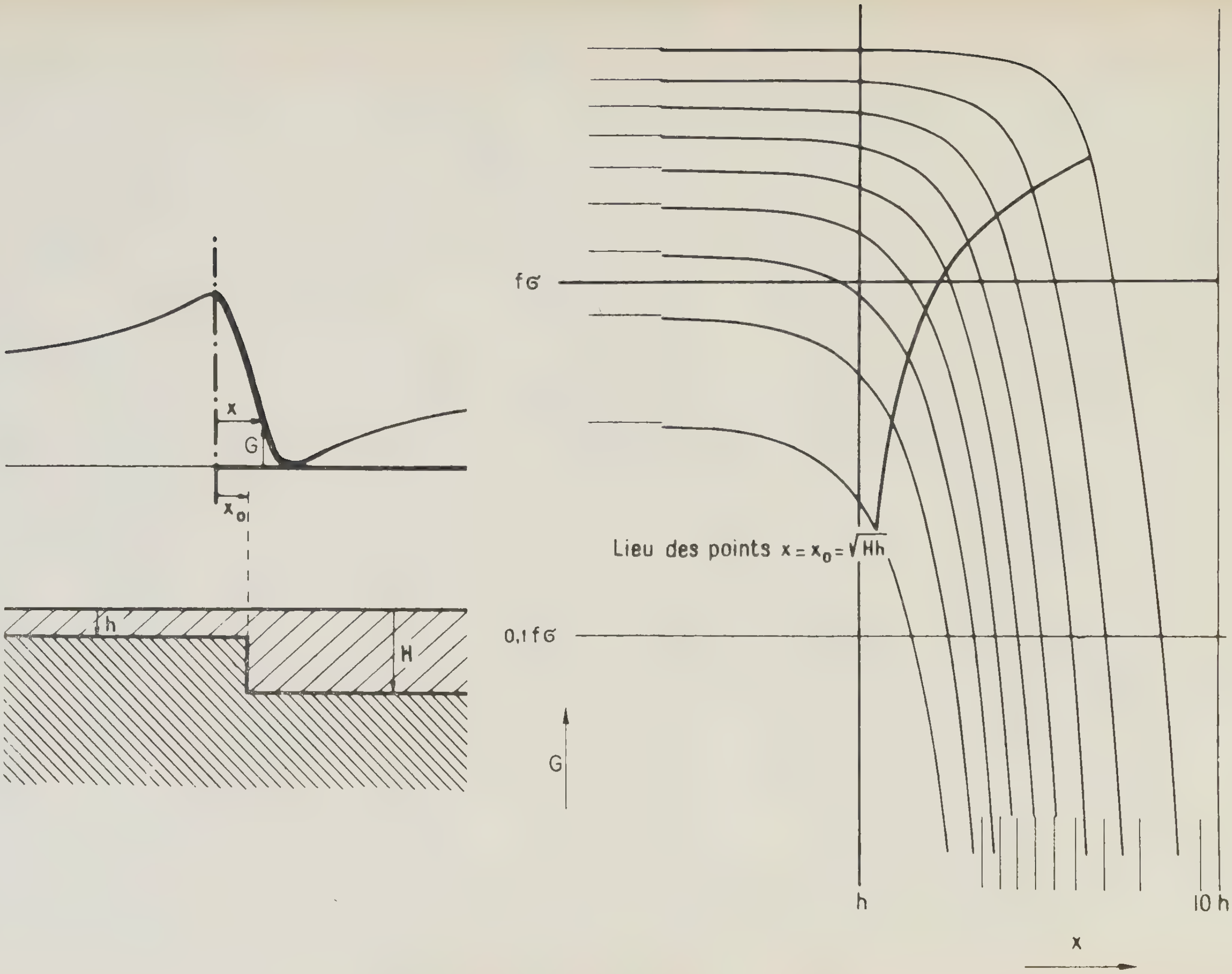


Fig. 6. Profil pangravimétrique *FVT* 90°; faille de rejet vertical. / Gravity master profile *FVT* 90°; vertical fault.

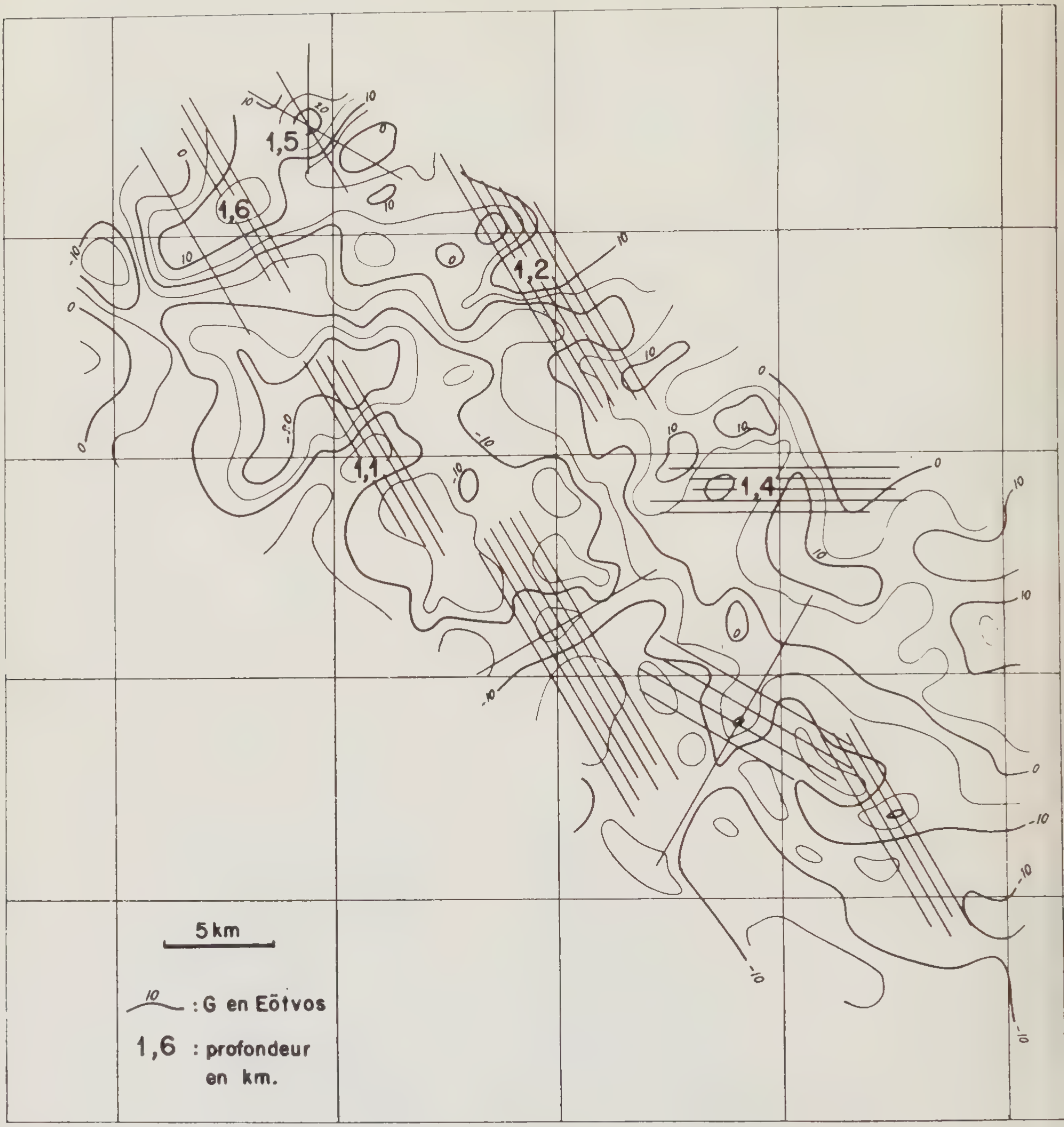


Fig. 7. Carte d'isanomales du gradient vertical de *g*, avec l'emplacement des coupes ayant servi à l'interprétation.
Iso anomaly map of vertical gradient of *g*, with the position of the sections used in the interpretation.

base supérieure. Pratiquement on l'utilise pour l'interprétation des anomalies de forme arrondie.

L'abaque du compartiment double carré infini vers le bas (figure 4) sert d'intermédiaire entre les deux cas extrêmes du compartiment cylindrique et du compartiment carré. On l'utilise pour l'interprétation des anomalies de forme assez allongée.

L'abaque des compartiments limités vers le bas (figure 5) est utilisé lorsque l'hypothèse du compartiment infini vers le bas est inacceptable. Les anomalies correspondantes se caractérisent par deux zones négatives situées de part et d'autre de l'anomalie principale.

L'abaque de la faille (figure 6) est utilisé très fréquemment; il permet de déterminer les différents paramètres géométriques et physiques caractérisant cet accident. Le lieu des points $x = \sqrt{Hh}$ donne simultanément la position du rejet et la moyenne géométrique des profondeurs H et h.

Voici maintenant un exemple réel: figure 7.

La carte représente les isanomales du gradient vertical de g, avec l'emplacement des coupes ayant servi à l'interprétation. L'emploi des abaques bilogarithmiques a permis de calculer la profondeur approximative de quelques accidents. Les nombres inscrits sur la carte représentent ces profondeurs évaluées en km.

II — INTERPRÉTATION MAGNÉTIQUE

Nous examinerons maintenant le cas du magnétisme et nous traiterons parallèlement le magnétisme à terre qui fait intervenir la composante verticale et l'aéromagnétisme qui fait intervenir le ,,champ total'', c'est-à-dire pratiquement la projection de l'anomalie sur la direction du champ terrestre normal: nous admettrons ici que cette direction est confondue avec celle de l'aimantation, ce qui correspond aux cas les plus courants.

1 — *La réduction au pôle*

L'interprétation directe d'une carte magnétique est un problème complexe que nous aborderons à la fin de cet article; nous montrerons auparavant qu'il y a souvent intérêt à simplifier le problème en ramenant l'interprétation du magnétisme à l'interprétation d'un gradient vertical de la gravimétrie telle que nous venons de la décrire.

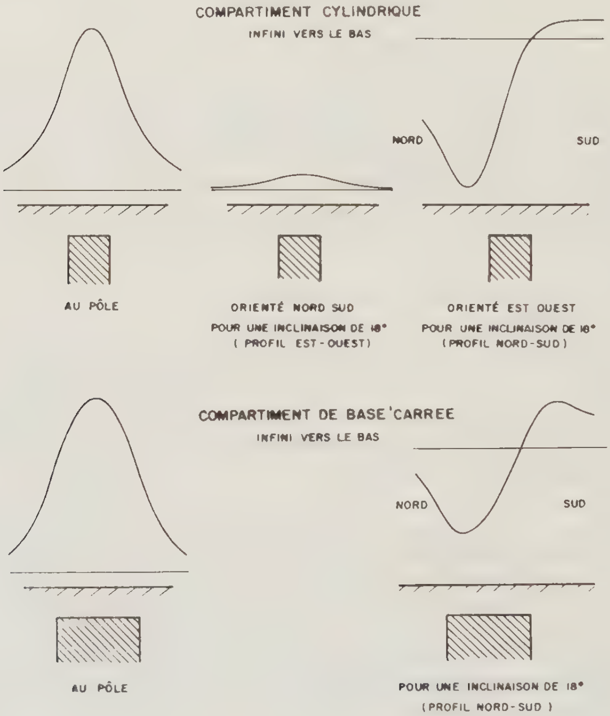
En effet, lorsque le champ inducteur est vertical, c'est-à-dire, pratiquement, au voisinage du pôle magnétique, la carte du champ magnétique est analogue à une carte du gradient vertical de la gravité. Bien entendu, la carte réelle du gradient de g et la carte du champ magnétique au voisinage du pôle ne sont pas identiques, car dans le premier cas les roches interviennent par leur densité et, dans le second cas, elles interviennent par leur susceptibilité magnétique. Mais l'interprétation des deux cartes se fait d'une manière identique et avec les mêmes abaques.

Le tableau I donne la correspondance entre les grandeurs qui interviennent dans le gradient vertical de la gravimétrie d'une part, dans l'anomalie magnétique d'autre part.

TABLEAU I

Gradient vertical G de g	*Anomalie magnétique au pôle*
$\frac{G}{f\sigma} = F\left(\frac{x}{h}, \frac{a}{h}\right)$	$\frac{\Delta Z}{\mathfrak{J}}$ ou $\frac{\Delta T}{\mathfrak{J}} = F\left(\frac{x}{h}, \frac{a}{h}\right)$
G: gradient vertical de g (exprimé en Eötvös)	ΔZ: anomalie de la composante verticale ΔT: anomalie du champ total (exprimées en γ)
$f\sigma$ (exprimé en Eötvös) σ : contraste de "densité" f : constante de la gravitation	$\mathfrak{J}$: contraste d'aimantation (exprimé en γ) $\mathfrak{J} = kH$ k : contraste de susceptibilité magnétique H : champ magnétique inducteur

TABLEAU II



Une carte magnétique relevée dans une région où le champ est peu incliné sur l'horizontale est plus complexe, mais M. Baranov (1957) a montré qu'on peut calculer ce que serait cette même carte si le champ était vertical, c'est-à-dire si l'on se trouvait au voisinage du pôle magnétique. La simplification ainsi introduite est considérable.

La partie supérieure du Tableau II représente les anomalies aéromagnétiques dues à un même compartiment cylindrique dans les trois cas suivants:

— Au pôle
— Pour une inclinaison de 18° (orientation Nord-Sud)
— Pour une inclinaison de 18° (orientation Est-Ouest)

La partie inférieure du Tableau II représente les coupes Nord-Sud des anomalies aéromagnétiques dues à un même compartiment de base carrée, au pôle et pour une inclinaison de 18°.

Ces exemples permettent de prévoir que sur une carte aéromagnétique relevée à la latitude magnétique de 18° les axes tectoniques de direction sensiblement Nord-Sud apparaîtront moins bien que les axes ayant d'autres directions; les structures localisées donneront sur cette même carte des anomalies complexes et nettement décalées.

Les mêmes structures, si elles étaient situées au pôle magnétique, produiraient des anomalies indépendantes de l'orientation et placées à la verticale de l'origine géologique. La carte serait beaucoup plus facile à lire et à interpréter.

Le calcul de réduction au pôle consiste en une transformation intégrale qu'on remplace pratiquement par une combinaison linéaire de valeurs relevées aux sommets d'une grille et affectées de coefficients judicieusement choisis. Le calcul est grandement facilité par l'emploi des calculatrices électroniques à cartes perforées.

Plutôt que d'entrer dans le détail de ces opérations, nous monterons quelques exemples d'application tirés d'une prospection aéromagnétique effectuée dans une région où l'inclinaison est voisine de 18°.

La figure 8 représente, en haut à gauche, une carte magnétique, et à droite la même carte réduite au pôle. Le tracé anguleux des courbes reflète la grille qui a servi au calcul.

La carte réduite au pôle met en évidence un axe important qu'on soupçonne à peine sur la carte aéromagnétique. La coupe AB a été interprétée au moyen d'un abaque bilogarithmique qui a permis de définir un compartiment compatible avec l'anomalie.

Sur la figure 9, l'anomalie aéromagnétique, à gauche, paraît importante, mais son interprétation n'est pas évidente. Au contraire, la carte transformée, à droite, montre une anomalie très simple et l'interprétation de la coupe *AB* est presque immédiate. L'application d'un abaque bilogarithmique permet de lui faire correspondre un compartiment limité vers le bas et très allongé dans le sens horizontal.

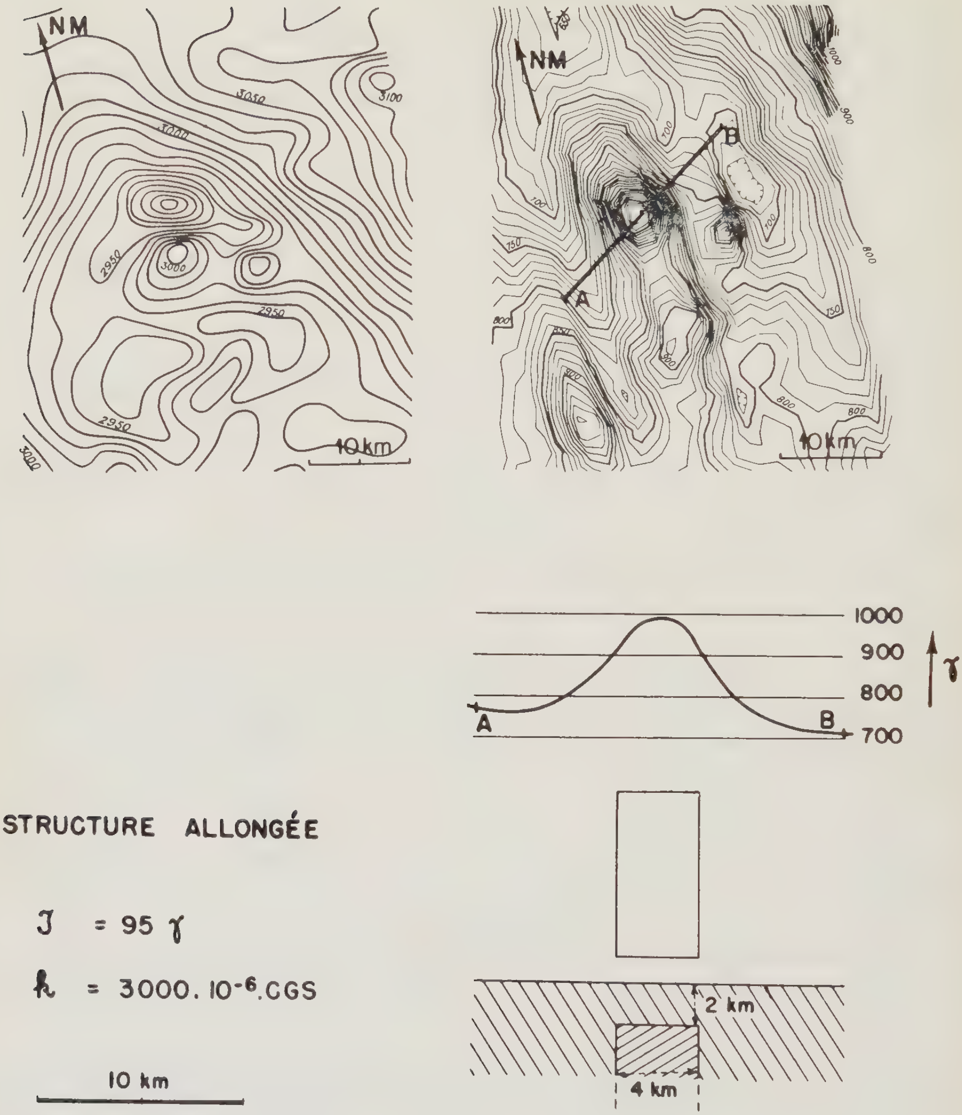


Fig. 8. Exemple d'interprétation d'une carte magnétique.
Example of interpretation of a magnetic map.

La figure 10 montre un exemple frappant du décalage des anomalies magnétiques par rapport à leur origine géologique. On voit sur la carte aéromagnétique, à gauche, une vaste anomalie couvrant presque toute la carte et, sur le flanc nord, une anomalie intense et très localisée. Sur la carte transformée,

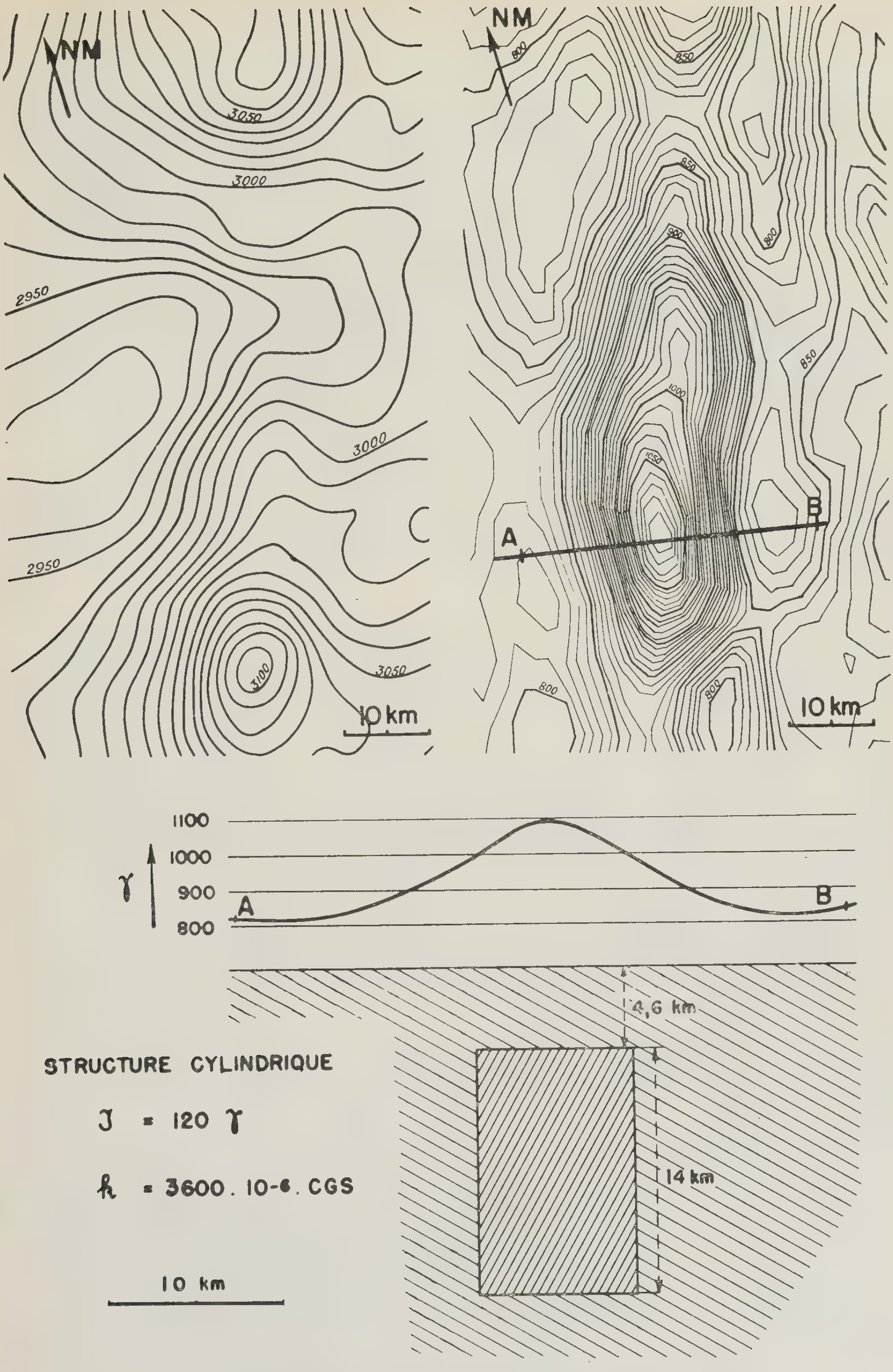


Fig. 9. Exemple d'interprétation d'une carte magnétique.
Example of interpretation of a magnetic map.

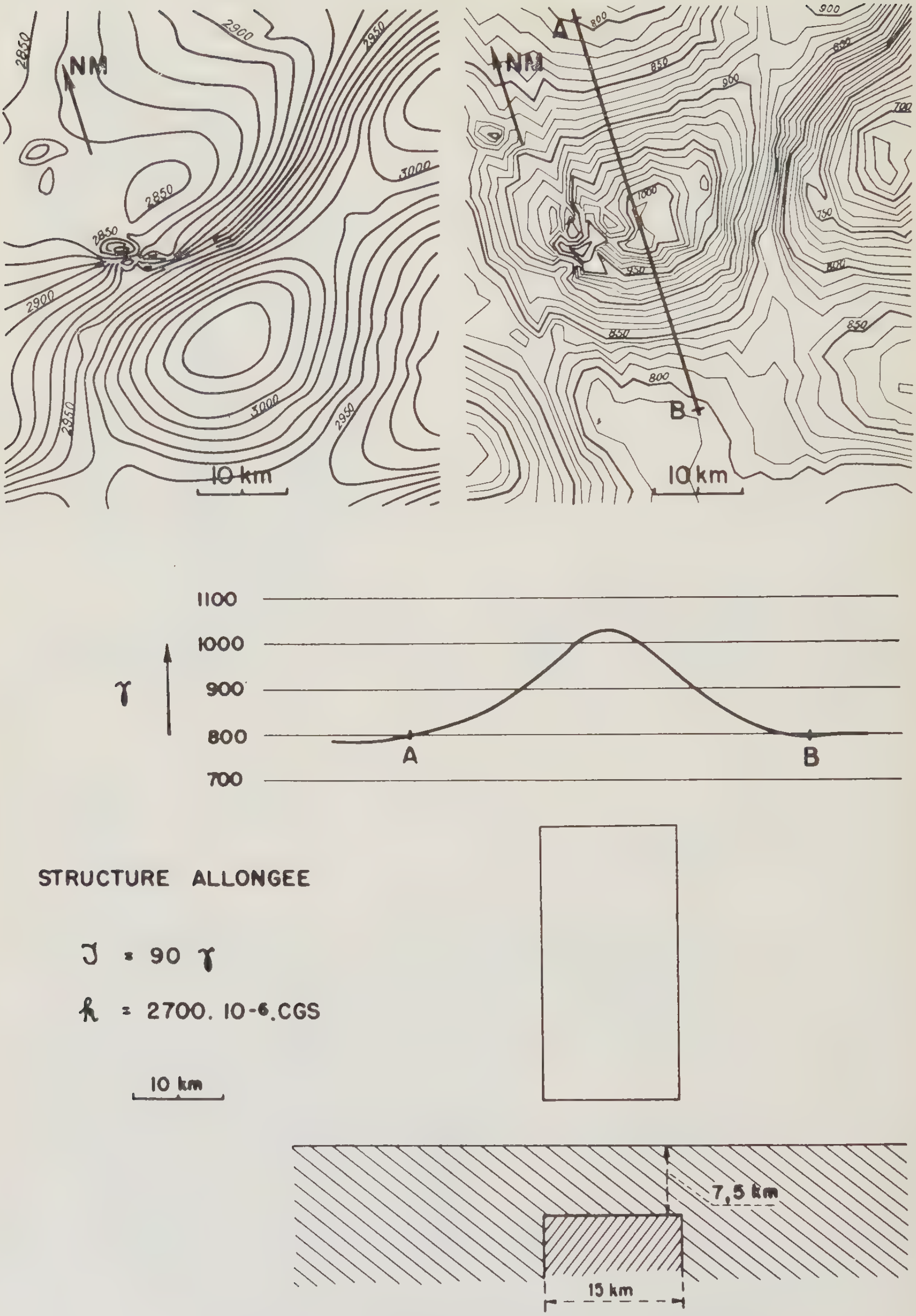


Fig. 10. Exemple d'interprétation d'une carte magnétique.
Example of interpretation of a magnetic map.

à droite, ces deux anomalies ont subi un déplacement relatif important: l'anomalie localisée — correspondant à un accident superficiel — n'a pratiquement pas bougé. La grande anomalie due à des roches profondes a subi un grand décalage. La carte transformée démontre donc que l'accident superficiel se trouve exactement à la verticale des roches profondes créant l'anomalie étendue.

2 — *L'interprétation directe*

Nous examinerons pour terminer l'interprétation directe des cartes magnétiques. Cette opération est intéressante parce qu'elle permet de travailler sur des documents originaux tels que les enregistrements du magnétomètre aéroporté.

Nous nous limiterons aux anomalies allongées, assimilables à des anomalies cylindriques, bien que la méthode puisse s'adapter à d'autres cas.

L'anomalie magnétique due à une structure donnée dépend de l'inclinaison du champ dans la région considérée et de l'orientation de la structure par rapport au méridien magnétique [1]).

a) Examinons d'abord *le cas des structures Est-Ouest.*

L'anomalie créée par une telle structure pour une inclinaison arbitraire i peut s'interpréter comme la combinaison linéaire des anomalies créées par cette même structure,

- — d'une part au pôle;
- — d'autre part, soit à l'équateur magnétique pour l'anomalie de la composante verticale, soit à l'inclinaison de 45° pour l'anomalie du champ total. Les coefficients de cette combinaison dépendent évidemment de l'inclinaison i.

C'est ce qui est schématisé dans le tableau III, à gauche pour une anomalie quelconque, à droite pour un exemple simple. Les composantes sont désignées respectivement par ΔT_1 et ΔT_2, la dernière ligne indique le résultat de la composition.

Nous avons rassemblé sous forme de tableau synoptique les anomalies typiques créées par les compartiments cylindriques et les failles Est-Ouest suivant l'inclinaison (Tableau IV). Ce tableau permet d'asseoir l'interprétation qualitative, c'est-à-dire de déterminer le type de structure correspondant à une anomalie expérimentale donnée. Les courbes désignées par la même lettre sont identiques à une symétrie près: cette propriété permet de limiter le nombre des courbes types à calculer.

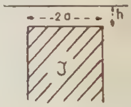
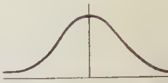
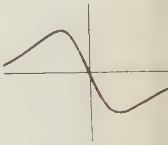
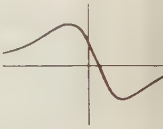
Ces courbes ont été transposées sous forme d'abaques bilogarithmiques

---

[1]) La démonstration des résultats énoncés dans ce paragraphe est donnée en annexe.

TABLEAU III

Structure est-ouest

Cas general:	*Exemple simple*: Compartiment cylindrique ∞ vers le bas	
au pôle $\Delta Z = \Delta T$: ΔT_1	$\Delta T_1 = 2\,\mathfrak{J}\,(\mathrm{Arctg}\,\frac{x+a}{h} - Arctg\,\frac{x-a}{h})$	
ΔZ à l'équateur magnétique: ΔT pour une inclinaison de 45°: } ΔT_2	$\Delta T_2 = \mathfrak{J}\,Log\,\frac{h^2+(x-a)^2}{h^2+(x+a)^2}$	
Pour une inclinaison i quelconque: $\Delta Z = \Delta T_1 \sin i + \Delta T_2 \cos i$ $\Delta T = - \Delta T_1 \cos 2i + \Delta T_2\, sin\, 2i$ $[\Delta Z$ pour $i] = [\Delta T$ pour $(45° + \frac{i}{2})]$	$0{,}309\,\Delta T_1 + 0{,}951\,\Delta T_2 =$ ΔZ pour l'inclinaison 18° ΔT pour l'inclinaison 54°	

utilisables aussi bien pour l'interprétation aéromagnétique que pour celle du magnétisme à terre.

La figure 11 montre à titre d'exemple la famille d'abaques des compartiments cylindriques Est-Ouest infinis vers le bas valables pour une inclinaison de 18° en magnétisme à terre et pour une inclinaison de 54° en aéromagnétisme. On a tracé comme sur les abaques précédents les lieux des points $x = a$, $x = h$, $\Delta T = \mathfrak{J}$ et, en outre, le lieu des points $x = x_0$ qui donne la position du centre de la structure, précaution indispensable puisque les anomalies ne sont pas symétriques.

On utilise ces abaques comme les abaques gravimétriques; par exemple, on lit ici $h = 5$ km, $a = 2$ km, $x_0 = 4$ km, $\mathfrak{J} = 40\gamma$.

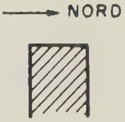
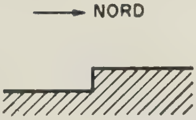
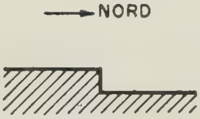
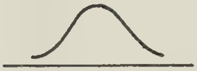
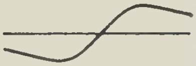
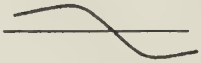
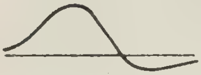
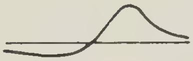
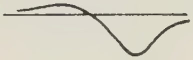
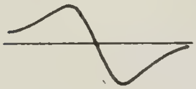
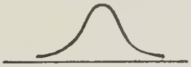
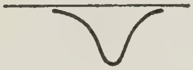
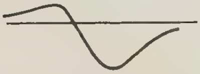
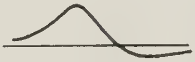
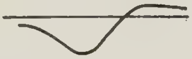
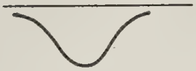
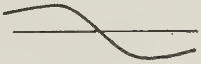
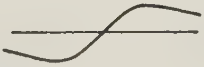
La figure 12 montre un abaque valable pour les failles de rejet vertical orientées Est-Ouest et situées dans des régions où l'inclinaison est de 72° dans le cas du magnétisme à terre, ou de 81° dans le cas de l'aéromagnétisme. L'abaque permet de déterminer la position du rejet de la faille et ses différents paramètres physiques et géométriques.

b) *Lorsque l'anomalie n'a pas la direction Est-Onest*, nous définissons son orientation par l'angle φ que font le méridien magnétique et le plan P perpen-

TABLEAU IV

Tableau synoptique - Structures orientées Est-Ouest

ANOMALIES MAGNETIQUES — HEMISPHERE NORD

INCLINAISON		COMPARTIMENT VERTICAL INFINI VERS LE BAS	FAILLE DE REJET VERTICAL	FAILLE DE REJET VERTICAL
magn. à terre	aéro magn.			
90° (pôle)		A 	D 	D 
i_0	$i_1 = 45° + \frac{i_0}{2}$	B 	E 	E 
0° Equat. magn.	45°	C 	F 	F 
/	$i_2 = 45° - \frac{i_0}{2}$	B 	E 	E 
/	0° Equat. magn.	A 	D 	D 

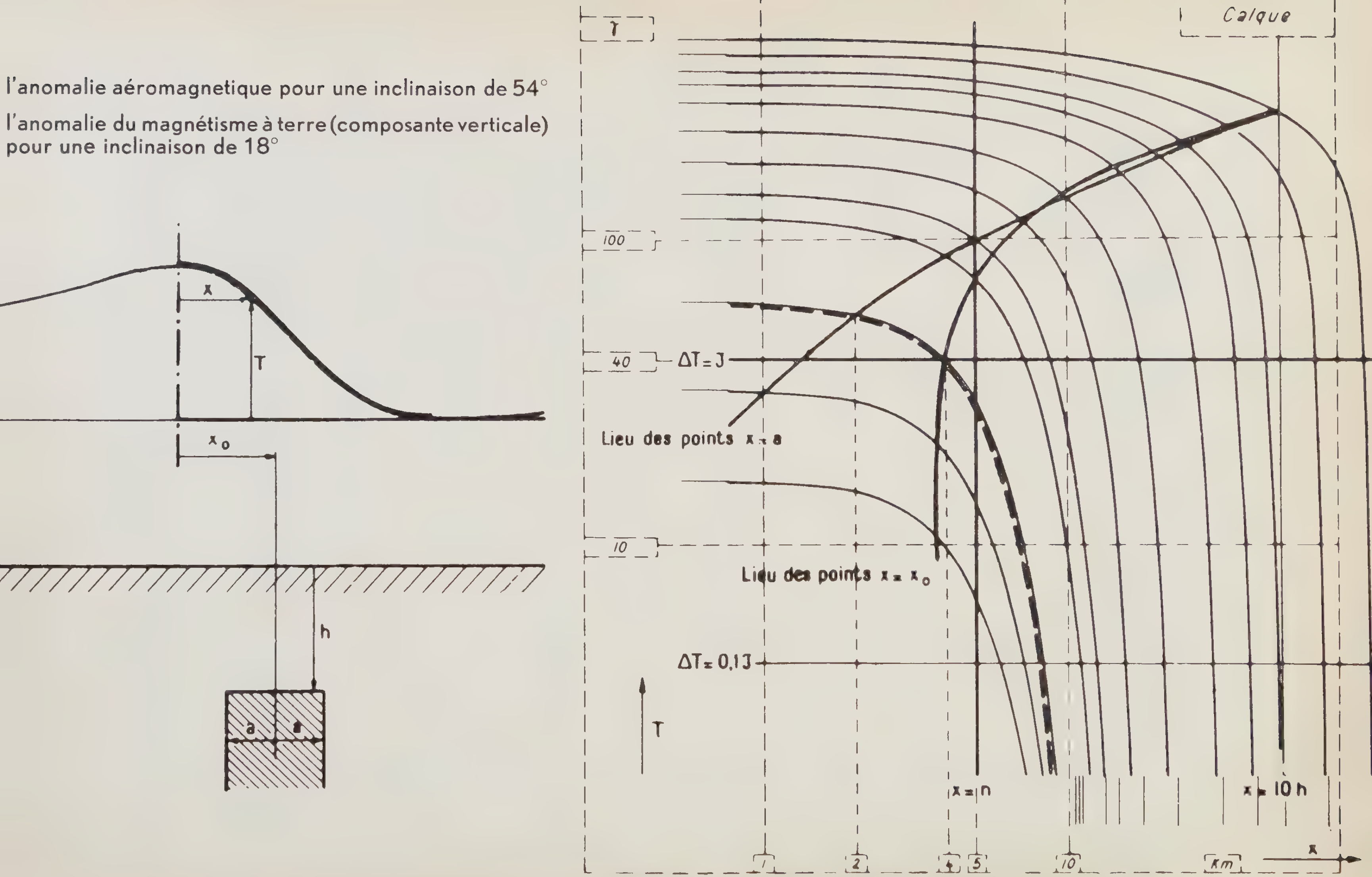


Fig. 11. Profil panmagnétique $CV \infty T - 54°$; compartiment cylindrique est-ouest vertical et infini vers le bas.
Magnetic master profile $VC \infty T - 54°$; cylindrical compartment with vertical walls, striking east-west and extending to infinite depth.

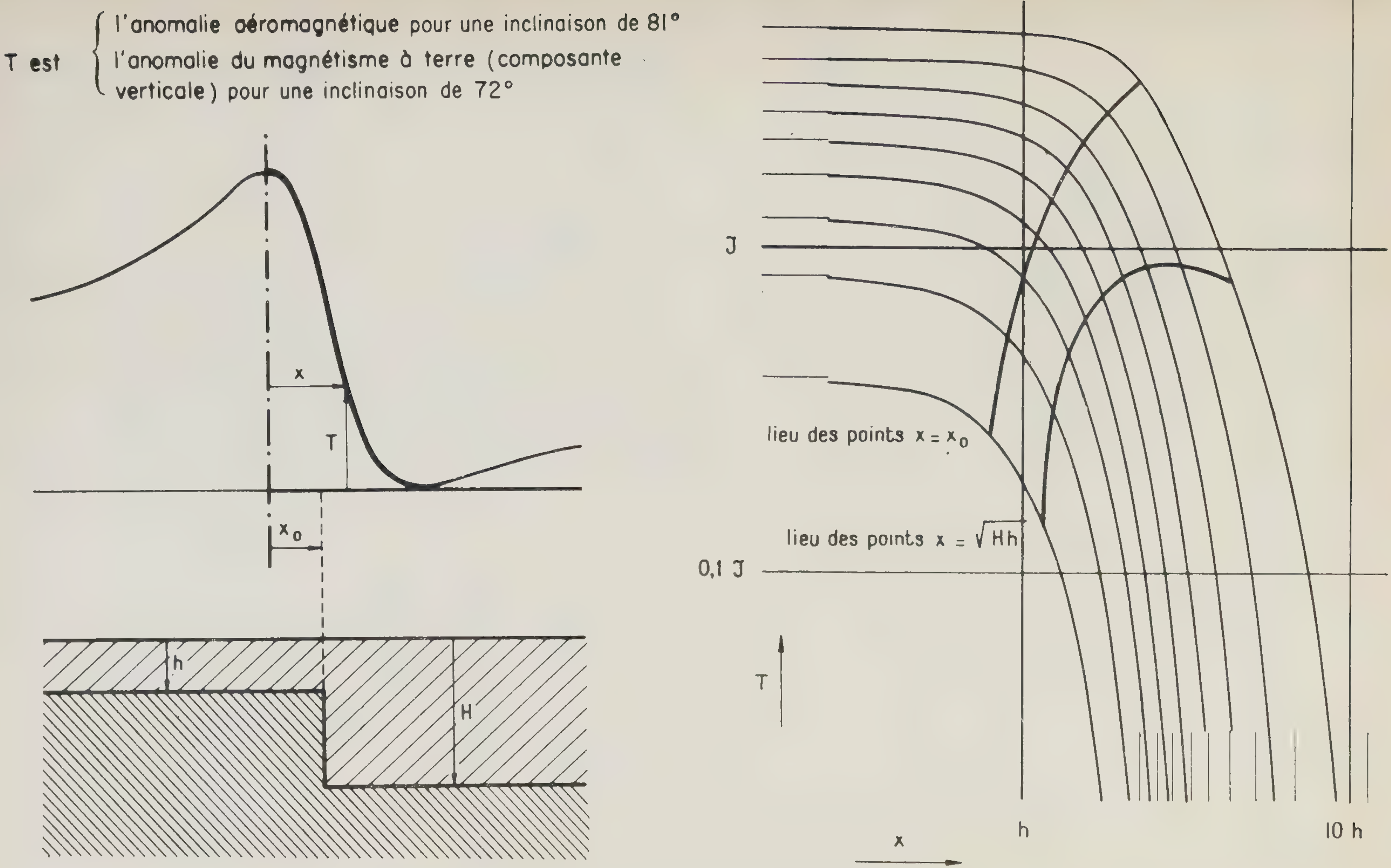


Fig. 12. Profil panmagnétique *FVT* 81°; faille est-ouest de rejet vertical.
Magnetic master profile *FVT* 81°; east-west trending vertical fault.

diculaire aux isanomales (figure 13). Nous introduisons aussi l'angle i' que nous appelons inclinaison apparente et qui n'est autre que la projection sur le plan P de l'inclinaison i.

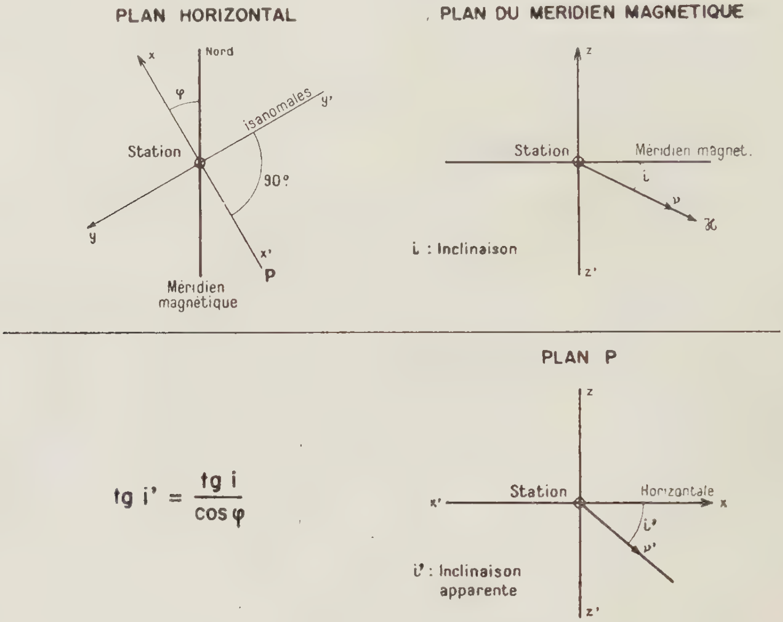


Fig. 13. Illustration de notations.
Illustration of notation.

Ces angles sont d'ailleurs liés par la relation

$$tg\, i' = tg\, i \,/\cos \varphi$$

Les anomalies ΔZ et ΔT sont alors données par les formules:

$$\Delta Z = \frac{\sin i}{\sin i'} (\Delta T_1 \sin i' + \Delta T_2 \cos i')$$

$$\Delta T = \left(\frac{\sin i}{\sin i'}\right)^2 (-\Delta T_1 \cos 2i' + \Delta T_2 \sin 2i')$$

qui montrent que le principe de la composition est encore valable à un facteur près.

On peut obtenir ces formules à partir de celles relatives aux structures orientées Est-Ouest (Tableau III) en remplaçant l'inclinaison i par l'inclinaison apparente i' et en multipliant les seconds membres par

$$\frac{\sin i}{\sin i'} \text{ pour } \Delta Z \text{ et par } \left(\frac{\sin i}{\sin i'}\right)^2 \text{ pour } \Delta T.$$

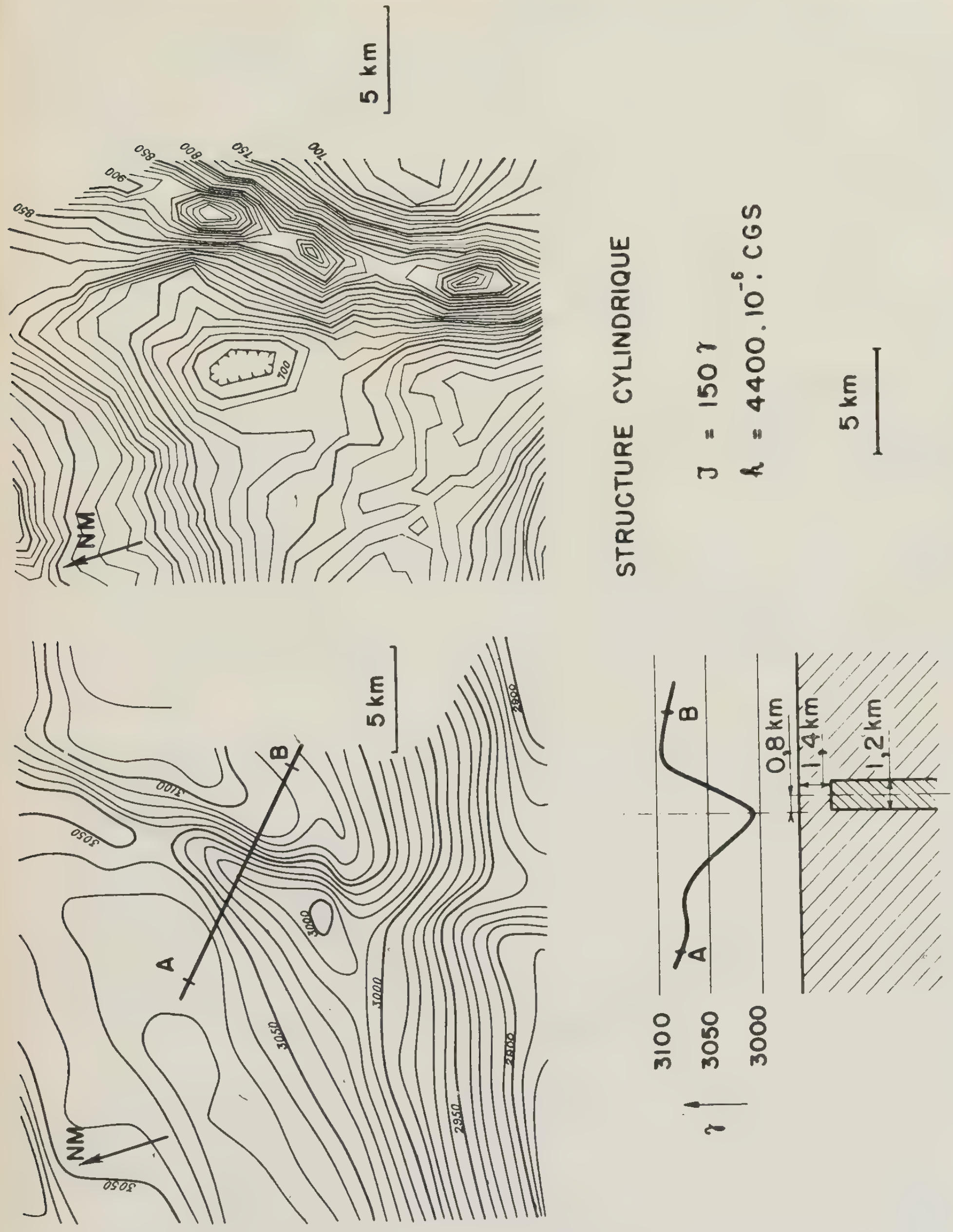


Fig. 14. Exemple d'interprétation d'une carte magnétique.
Example of interpretation of a magnetic map.

Pour interpréter une anomalie magnétique, on commence donc par déterminer i et φ; on calcule i' par la formule $\mathrm{tg}i' = \mathrm{tg}i/\cos\varphi$, et l'on effectue l'interprétation avec les mêmes abaques que précédemment comme s'il s'agissait d'une anomalie Est-Ouest pour une inclinaison i'. Les résultats trouvés pour les grandeurs géométriques (profondeur, largeur, ...) sont valables; la valeur de l'aimantation doit être multipliée

— par $\dfrac{\sin i'}{\sin i}$ dans le cas du magnétisme à terre

— par $\left(\dfrac{\sin i'}{\sin i}\right)^2$ dans le cas de l'aéromagnétisme

La figure 14 montre un exemple concret.

La carte aéromagnétique a été interprétée directement. L'inclinaison magnétique est de l'ordre de 18°. L'application de la formule $\mathrm{tg}i' = \mathrm{tg}i/\cos\varphi$ conduit à la valeur de 25° pour l'inclinaison apparente. L'examen du tableau synoptique montre que pour cette inclinaison la courbe AB est analogue à l'anomalie d'un compartiment cylindrique infini vers le bas. L'application de l'abaque bilogarithmique correspondant permet de déterminer les caractéristiques de ce compartiment. On a représenté à droite la carte réduite au pôle qui confirme l'interprétation directe de la carte aéromagnétique.

CONCLUSION

Les méthodes que nous venons de décrire présentent sur celles que nous connaissions déjà deux avantages principaux. Elles sont synthétiques, en ce sens qu'elles utilisent une courbe ou un arc de courbe dans son ensemble, et rigoureuses en ce sens qu'appliquées à des cas théoriques, elles conduisent à des résultats exacts.

Bien entendu, elles sont susceptibles de rendre des services plus appréciables si elles sont employées simultanément. En particulier, la comparaison des interprétations d'une carte du gradient vertical de g et d'une carte magnétique réduite au pôle présente un grand intérêt des deux points de vue qualitatif et quantitatif.

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ANNEXE

DEMONSTRATION DE QUELQUES RESULTATS RELATIFS AUX STRUCTURES CYLINDRIQUES

Nous considérerons seulement le cas de l'hémisphère Nord (on démontre aisément que les formules sont identiques dans l'hémisphère Sud) et nous commencerons par récapituler et compléter nos notations (Fig. 13).

L'axe $z'z$ est dirigé vers le haut.

P est le plan perpendiculaire aux génératrices de la structure. x'x est l'horizontale du plan P dirigée du côté du Nord

φ est l'angle du méridien magnétique et du plan P (angle arithmétique compris entre 0° et 90°).

$\vec{\nu}$, de composantes α, β, γ, est le vecteur unitaire de la direction du champ terrestre normal.

$\vec{\nu}'$ est sa projection sur le plan P.

i est l'inclinaison du champ terrestre normal.

i' est la projection de i sur le plan P.

Ces angles sont liés par la relation $tg\, i' = tg\, i/\cos\varphi$

$\vec{\nu}_1$, de composantes α_1, β_1, γ_1 est le vecteur unitaire de l'axe sur lequel on mesure la composante du champ.

Dans le cas de l'aéromagnétisme $\alpha_1 = \alpha \quad \beta_1 = \beta \quad \gamma_1 = \gamma$

Dans le cas du magnétisme à terre $\alpha_1 = 0 \quad \beta_1 = 0 \quad \gamma_1 = -1$

$\vec{\mathfrak{J}}$ représente l'aimantation; nous admettrons que sa direction est celle du champ terrestre normal: $\vec{\mathfrak{J}} = \mathfrak{J}\vec{\nu}$.

L'intensité d'aimantation $\mathfrak{J}$ est supposée constante à l'intérieur de la structure considérée 1).

Le moment magnétique d'un élément de volume au point A (fig. 15)

$$\overrightarrow{dM_A} = \vec{\mathfrak{J}}\, dv_A = \vec{\nu}\, \mathfrak{J}\, dv_A$$

crée en M un potentiel

$$dV_M = -\overrightarrow{dM_A} \cdot \overrightarrow{grad_M}\,(1/r) = -\mathfrak{J}\,\vec{\nu}\,\overrightarrow{grad}_M\,(1/r)\, dv_A. \qquad r = |MA|$$

L'ensemble de la structure crée donc en un point extérieur le potentiel

$$V_M = -\mathfrak{J} \iiint \vec{\nu} \cdot \overrightarrow{grad_M}(1/r)\, dv_A.$$

---

1) Dans le cas du magnétisme à terre, comme dans celui de l'aéromagnétisme, $\mathfrak{J} = kH$ avec $H = \sqrt{H_0^2 + Z_0^2}$
(k susceptibilité magnétique,
H_0 et Z_0 composantes horizontale et verticale du champ normal terrestre).

Il est commode d'introduire la quantité

$$U = -\mathfrak{J} \iiint \frac{dv}{r}$$

qui représente un potentiel newtonien [1]).

On aboutit alors pour V, à l'expression

$$V = \frac{dU}{d\nu}$$

La composante, dans la direction $\overrightarrow{\nu_1}$, du champ créé par ce potentiel est

$$(\Delta T)_{\nu_1} = -\frac{dV}{d\nu_1} = -\frac{d^2U}{d\nu \,.\, d\nu_1}$$

Cette expression peut être facilement explicitée, en effet

$$\frac{dU}{d\nu} = \alpha \frac{\partial U}{\partial x} + \gamma \frac{\partial U}{\partial z}$$

car $dU/dy = 0$ pour une structure cylindrique dont les génératrices sont parallèles à $0y$

De même

$$\frac{d^2U}{d\nu \,.\, d\nu_1} = \alpha\alpha_1 \frac{\partial^2 U}{\partial x^2} + (\alpha\gamma_1 + \alpha_1\gamma) \frac{\partial^2 U}{\partial x.\partial z} + \gamma\gamma_1 \frac{\partial^2 U}{\partial z^2}$$

Le potentiel U étant harmonique,

$$\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial z^2} = 0$$

et

$$(\Delta T)_{\nu_1} = (\alpha\alpha_1 - \gamma\gamma_1) \frac{\partial^2 U}{\partial z^2} - (\alpha\gamma_1 + \alpha_1\gamma) \frac{\partial^2 U}{\partial x.\partial z}$$

Dans le cas de l'aéromagnétisme,

$$\Delta T = (\alpha^2 - \gamma^2) \frac{\partial^2 U}{\partial z^2} - 2\,\alpha\gamma \frac{\partial^2 U}{\partial x.\partial z}\,.$$

Dans le cas du magnétisme à terre

$$\Delta Z = \gamma \frac{\partial^2 U}{\partial z^2} + \alpha \frac{\partial^2 U}{\partial x.\partial z}$$

En utilisant les relations:

$$\sin i = -\gamma \qquad \cos i' = \frac{\alpha}{\sqrt{\alpha^2+\gamma^2}} \qquad \sin i' = -\frac{\gamma}{\sqrt{\alpha^2+\gamma^2}}$$

---

[1]) U n'est autre que le potentiel pseudo-gravimétrique: V. Baranov—A new method for interpretation of Aeromagnetic maps: pseudo-gravimetric anomalies, Geophysics 1957.

on démontre facilement que les expressions précédentes peuvent s'écrire:

$$\left\{\begin{aligned} \Delta T &= \frac{\sin^2 i}{\sin^2 i'}\left(\frac{\partial^2 U}{\partial z^2}\cos 2i' + \frac{\partial^2 U}{\partial x.\partial z}\sin 2i'\right) \\ \Delta Z &= \frac{\sin i}{\sin i'}\left(-\frac{\partial^2 U}{\partial z^2}\sin i' + \frac{\partial^2 U}{\partial x.\partial z}\cos i'\right) \end{aligned}\right.$$

Dans le cas des structures Est Ouest $\varphi = 0$, $i' = i$

$$\left\{\begin{aligned} \Delta T &= \frac{\partial^2 U}{\partial z^2}\cos 2i + \frac{\partial^2 U}{\partial x.\partial z}\sin 2i \\ \Delta Z &= -\frac{\partial^2 U}{\partial z^2}\sin i + \frac{\partial^2 U}{\partial x.\partial z}\cos i \end{aligned}\right.$$

Au pôle magnétique $i = 90°$ $\quad \Delta T = -\frac{\partial^2 U}{\partial z^2}$ $\quad \Delta Z = -\frac{\partial^2 U}{\partial z^2}$

A l'équateur magnétique $i = 0°$ $\quad \Delta Z = \frac{\partial^2 U}{\partial x.\partial z}$

Pour une inclinaison $i = 45°$ $\quad \Delta T = \frac{\partial^2 U}{\partial x.\partial z}$

Nous posons $\Delta T_1 = -\frac{\partial^2 U}{\partial z^2}$ (cette quantité représente l'anomalie du champ total ou de la composante verticale au pôle magnétique).

$\Delta T_2 = \frac{\partial^2 U}{\partial x.\partial z}$ (cette quantité représente dans le cas de structures Est-Ouest l'anomalie du champ total pour une inclinaison de 45° ou l'anomalie de la composante verticale à l'équateur magnétique).

Les expressions relatives aux structures Est-Ouest s'écrivent alors:

$$\left\{\begin{aligned} \Delta T &= -\Delta T_1 \cos 2i + \Delta T_2 \sin 2i \\ \Delta Z &= \Delta T_1 \sin i + \Delta T_2 \cos i \end{aligned}\right.$$

On voit que ΔT et ΔZ sont des combinaisons linéaires de ΔT_1 et ΔT_2 et on vérifie aisément que

$$[\Delta Z \text{ pour } i] = [\Delta T \text{ pour } (45° + \frac{i}{2})]$$

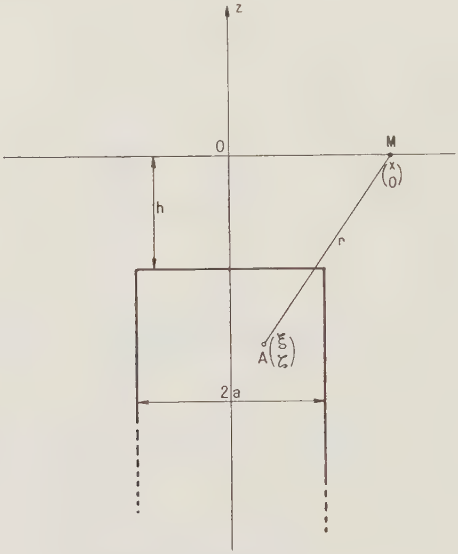
Dans le cas des structures d'orientation quelconque,

$$\left\{\begin{aligned} \Delta T &= \frac{\sin^2 i}{\sin^2 i'}(-\Delta T_1 \cos 2i' + \Delta T_2 \sin 2i') \\ \Delta Z &= \frac{\sin i}{\sin i'}(\Delta T_1 \sin i' + \Delta T_2 \cos i') \end{aligned}\right.$$

On voit qu'on peut obtenir ces formules à partir de celles relatives aux structures Est-Ouest en remplaçant i par i′ et en multipliant les seconds membres

$$\text{par } \frac{\sin i}{\sin i'} \text{ pour } \Delta Z \text{ et par } \frac{\sin^2 i}{\sin^2 i'} \text{ pour } \Delta T$$

Il resterait à démontrer les formules explicitant ΔT_1 et ΔT_2 dans le cas du compartiment cylindrique à parois verticales (dyke) — nous indiquerons simplement les principales étapes du calcul (Fig. 15).



Compartiment cylindrique infini vers le bas

Fig. 15. Illustration de notations.
Illustration of notation.

$$\Delta T_1 = \mathfrak{J} \iiint \frac{\partial^2}{\partial \mathfrak{z}^2} \left(\frac{1}{r}\right) d\xi \, d\eta \, d\zeta = \mathfrak{J} \iiint \frac{2\zeta^2 - (\xi - x)^2 - (\eta - y)^2}{[(\xi - x)^2 + (\eta - y)^2 + \zeta^2]^{5/2}} \, d\xi \, d\eta \, d\zeta$$

$$= -2 \mathfrak{J} \iint \frac{(\xi - x)^2 - \zeta^2}{[(\xi - x)^2 + \zeta^2]^2} \, d\xi \, d\zeta = 2 \mathfrak{J} \left[\text{Arc tg} \frac{x + \alpha}{h} - \text{Arc. tg} \frac{x - \alpha}{h}\right]$$

(Arc tg détermination principale)

$$\Delta T_2 = - \mathfrak{J} \iiint \frac{\partial^2}{\partial x . \partial \mathfrak{z}} \left(\frac{1}{r}\right) d\xi d\eta d\zeta = -3 \mathfrak{J} \iiint \frac{(\xi - x) \, \zeta}{[(\xi - x)^2 + (\eta - y)^2 + \zeta^2]^{5/2}} \, d\xi \, d\eta \, d\zeta$$

$$= -4 \mathfrak{J} \iint \frac{(\xi - x) \, \zeta}{[(\xi - x)^2 + \zeta^2]^2} \, \mathrm{d}\xi \, \mathrm{d}\zeta = \mathfrak{J} \, \text{Log} \frac{h^2 + (x - \alpha)^2}{h^2 + (x + a)^2}$$

(Log = logarithme népérien)

DENSITY DETERMINATION ON NEAR-SURFACE LAYERS BY GAMMA ABSORPTION *)

BY

J. HOMILIUS **) AND S. LORCH **)

ABSTRACT

From gamma ray absorption the density of soil to a depth of 1 m. can be determined in situ, without taking samples, by a method which has been described in a previous paper (Wendt 1954) and which has been checked with satisfactory results (mean error about 1%). A nearly vertical steel rod with a gamma ray source at its lower end is pushed into the ground, and the gamma radiation is measured at the surface with two counters placed symmetrically with respect to the rod.

As a first step in interpreting the observed effects, the assumption had been made that counters are infinitesimally small. This paper shows how a theory can be developed without this assumption, the finite dimensions of the counters being taken into account by an integral expression. For this purpose a determination of the dependence of the counting rate on the angle of incidence of the gamma rays is required. A comparison of the experimental results with the theoretical ones demonstrates that the integral expression is correct.

The influence of deviations from the normal geometry of the arrangement (e.g. caused by bending of the probe) on the results is investigated, as well as the influence of variations of the density with depth.

The treatment of the basic problems has been carried through in such a manner that the results obtained can be applied to other absorption methods as well.

NOTATIONS USED IN TEXT AND FIGURES

A	mass number
a	distance between the axis of the two counters of the density meter (Fig. 1)
C'	unit of the strength of radiation (1 Curie = $3, 7 . 10^7$ disintegrations per sec.)
δ	shortening of the absorption way of the radiation due to counter diameter and aluminium base plate
d	effective diameter of a counter
k	first argument of the integral W (k, cos ϑ)
l	effective length of a counter

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*) Presented at the Twelfth Meeting of the European Association of Exploration Geophysicists, held in Brussels, 5-7 June 1957; extended section from LORCH's thesis, presented to the Bergakademie Clausthal, 1956.

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μ	absorption coefficient (according to (2) and (8))
μ'	$= \mu/\rho$
$\bar{\mu}$	"apparent" absorption coefficient (according to (12))
$\bar{\mu}'$	$= \mu/\rho$
N	counting rate, also $\tilde{N}$, $\overline{N}$
N_a	number of atoms per unit of volume
N_0	total number of non-scattered quants of a source S in a stationary system
n	AVOGADRO number
Q	abbreviation according to (8), $\overline{Q}$ according to (12)
q	sensitivity of a counter
q_0	sensitivity for an incidence of radiation perpendicular to the counter axis
ρ	density
r, ϑ, φ	polar coordinates with the radiation source S as origin
r_0	shortest distance between a source and the axis of a counter, the upper subscript 1, 2, . . . ($r_0^{(1)}$, $r_0^{(2)}$, . . .) indicates the segment in the soil of the density ρ_1, ρ_1, . . .
r_1	$= (r_0^2 + l^2/4)^{1/2}$
S	location of the radiation source
σ	cross section of an electron
W	integral with the arguments k and cos ϑ (defined in (9))
$\tilde{W}$, $\tilde{\tilde{W}}$	first and second derivative of W with respect to k
w	thickness of a counter wall
Z	atomic number
z	vertical coordinate, depth of the source

INTRODUCTION

New knowledge from atomic research has resulted in a number of modern methods of density measurements, particularly in the field of foundation investigation and hydrological problems. The principal defects of the earlier methods employing samples were thereby overcome and, in addition to a quicker measuring process, a remarkable increase in accuracy was obtained. The improvements are chiefly due to the application of gamma rays from artificial radioactive isotopes.

The interaction between gamma rays and matter can be used for density measurement in situ in two different ways, (1) by determining the absorption in a fixed geometric arrangement. This, for example, is the basis of the methods due to Lorenz and Neuber (1954) and to Wendt (1954), and (2) by measuring the scattered radiation in such a way that the direct radiation is intercepted.

For instance, Belcher in America (1952) and Wendt and Wolters in Germany (1956) worked on such density meters.

Both methods produce, after a preliminary calibration of the apparatus, the density of the irradiated soil including the degree of moisture (density of moist places).

Strictly speaking, the "electron density" and not the density of matter is determined but, with the various atoms (Si, O, Mg, Fe, Ca, Al) normally making up the composition of the soil, the ratio of electron number to mass number is a half, with sufficient accuracy for elements having atomic numbers up to about $Z = 26$ (Fe) (with the exception $Z = 1$). The small weight fraction of the "anomalous" hydrogen does not allow the measurement of the water content, even if radiations of different hardnesses are used. In order to determine the dry density, an additional measurement of the water content by other methods is necessary (scattering of slow neutrons, see Belcher (1952)).

1. *The Density Meter*

In the following, the theory will be treated of a method for which Wendt (1954) has performed the fundamental experimental work. With the arrangement under review (Fig. 1), a metal probe, of diameter about 1 cm., with a radio-isotope at its lower end is driven nearly vertically into the soil, and the absorption of the gamma radiation is measured by two counters of 50 cm effective length. These counters, with a distance of 70 cm between them, are placed symmetrically about the metal rod on an aluminium base plate resting on the ground.

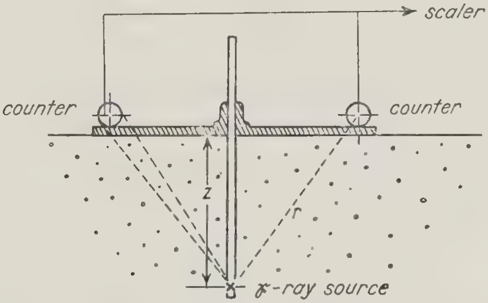

Fig. 1. Density meter

The source was either Co^{60} or Cs^{137} of 20 or 30 mC′ respectively, with which layers up to 1 m thickness can be investigated. Co^{60} emits the harder rays, having 1,17 and 1,33 MeV components with a half life of 5,26 yr. Cs^{137}, with a half life of 33 yr changes, through beta disintegration, to an excited Ba^{137}

which, in its turn and with a half life of 2,6 min, changes over into a stable Ba^{137} with radiation of a 0,66 *MeV* gamma quantum.

In the paper by Wendt (1954), we find the initial steps for a theoretical treatment of the dependence of counting rates on the geometry of the arrangement, limited, however, to the case of counters of infinitely small volume. For the purpose of averaging inhomogenities of the soil and for getting reasonable measuring times with moderate radiation sources, however, one must employ counters as large as possible. For this important practical case, the present investigations became necessary.

2. *The Spatial Distribution of Gamma Quanta*

The counting rate at a large counter depends on the distribution of intensity of the gamma quanta and on the efficiency of the counter itself.

If we place the source at the origin of a polar coordinate system (Fig. 2),

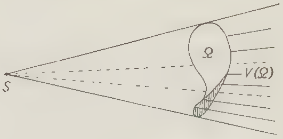

Fig. 2. Radiation on a counter surface

the spatial distribution of unscattered quanta for a stationary system is determined by the strength of the radiation source *S*, by the divergence of the radiation cone and by the absorption losses, involving the absorption coefficient μ. We can therefore express the number of quanta per unit of volume about the point (r, ϑ, φ) as

$$N_{\vartheta,\varphi}(r) = N_0 \frac{\mu}{4\pi r^2} e^{-\mu r}. \qquad (1)$$

These constants are determined in such a way that the integration over the whole space yields the total number of unscattered quanta N_0.

The absorption coefficient μ depends, through the electronic effective cross section σ, 1) upon the hardness of the radiation, and upon the number of scattering centres, i.e. upon the number of electrons $N_a \cdot Z$ in unit of volume, so

$$\mu = N_a \cdot Z \cdot \sigma. \qquad (2)$$

N_a is the number of atoms per unit volume with atomic number Z. Using

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1) With the applied radiation, the component which originates from the Compton scattering predominates in σ. σ is therefore proportional to the integrated Klein-Nishina-Formula.

the ratio A/n of the atomic weight A and Avogadro's number n, it is easily to be seen that μ is proportional to the density ρ or

$$\mu = \mu' \cdot \rho \text{ with } \rho = \frac{N_a}{n} \,.\, A \text{ and } \mu' = n \,.\, \frac{Z}{A} \,.\, \sigma \tag{3}$$

As already mentioned, $A/Z = 2$, so that μ theoretically only depends upon the hardness of the radiation. It is evident, though, that the numerical value of μ' is not independent on the test conditions (Kohlrausch 1928). For the integral representation of the counting rate derived in this paper, the mean values are computed by comparison with the measuring graphs (section 6):

$$\left(\frac{1}{\mu'}\right)_{Co^{60}} = 18{,}4\ g\,.\,cm^{-2};\ \left(\frac{1}{\mu'}\right)_{Cs^{137}} = 14.2\ g\,.\,cm^{-2}. \tag{4}$$

3. *The Direction Sensitivity of Counters*

The counter sensitivity is—seen spatially—a function of the angle of incidence of the radiation upon the counter wall. For the purpose of determining empirically this relation, two test series were carried out, the results of which are represented in the figures 3 and 4.

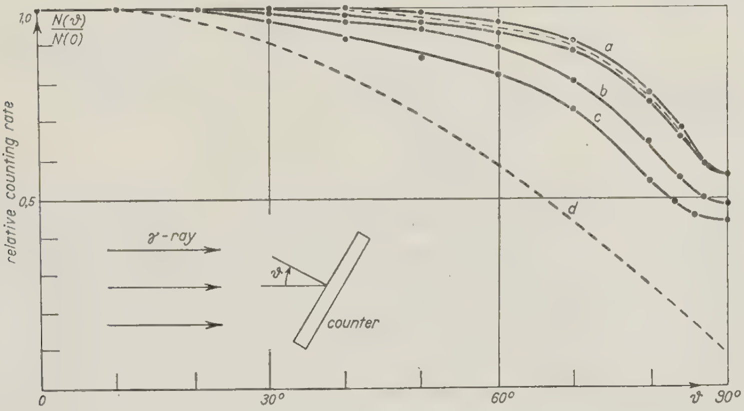

Fig. 3. Relative counting rate as a function of the angle ϑ with a *a*) gamma micro counter, *b*) cosmic ray counter (50 cm), *d*) cosmic ray counter (25 cm), *d*) curve according to equation (5) for the gamma micro counter

If a parallel pencil of gamma rays strikes a counter (Fig. 3), then the counting rate as a function of the angle ϑ is much less dependent upon this angle than the corresponding projection of the counter surface

$$F(\vartheta) = F(o) \left\{ \cos\vartheta + \frac{\pi d}{4l} \sin\vartheta \right\}, \tag{5}$$

which is plotted for the counter a as curve d in figure 3. The curves, measured with three different counters, up to an angle of 45° [1]) lie so near to 1 that in this range of ϑ the sensitivity can be taken as proportional to $1/\cos \vartheta$, because the decrease of the counter projection, according to (5), is nearly proportional to $\cos \vartheta$. The tests were carried out with a distance of 6 m from the counter to the gamma source, assumed to be a point source (Co^{60} with about 20 mC') and the counters were turned around their centre points.

If a pencil of radiation limited by stops to 0,2 mm width and parallel to the counter axis strikes a counter, then the counting rate depends upon the distance of the pencil from the counter centre (Fig. 4) (compare also Maier-Leibnitz 1942).

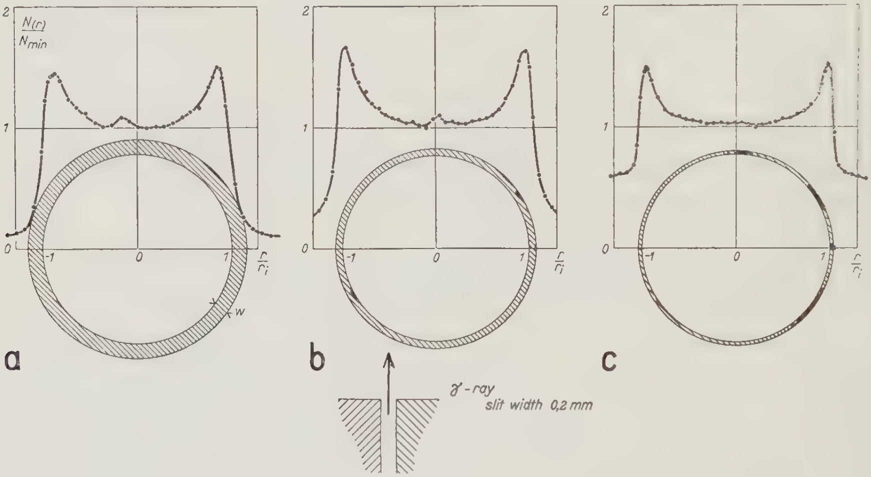

Fig. 4. Distribution of sensitivity along the diameter of three typical counters. *a*) end-window counter (N_{min} = 1390 cpm, $2r_i$ = 21,3 mm, w = 1,75 mm), *b*) cosmic ray counter (N_{min} = 6260 *cpm*, $2r_i$ = 28,1 mm, w = 0.95 mm), *c*) C^{14}-counter (N_{min} = 6500 cpm, $2 r_i$ = 54,0 mm, w = 1,00 mm)

With all three counters, the maxima of the counting rates lie, near to and within the walls. The weak secondary maximum occurring in the centre of the otherwise symmetrical curve is due to the direct impact of the gamma rays on the counter wire. The increase of the counting rate at the wall must be considered in the theory of very accurate interpretations, but not in the case when the diameter of the counter is small compared with the distance to the source. Since the latter condition is usually the case in our observations, we can assume a constant counter efficiency parallel to the diameter.

Without going into details it should be mentioned that to a certain degree the observations shown in the last two figures can be interpreted qualitatively by the quantum theory. We can now formulate the sensitivity of a cylindrical counter with

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[1]) Maier-Leibnitz (1946) observed an independency of angle widely exceeding even 45°.

$$q\,(\vartheta, \varphi) = \frac{q_o}{\cos \vartheta}\,[1 + \text{small terms in } \vartheta^2 \text{ and } \varphi^2] \tag{6}$$

for which Fig. 5 shows the position of the angles ϑ and φ.

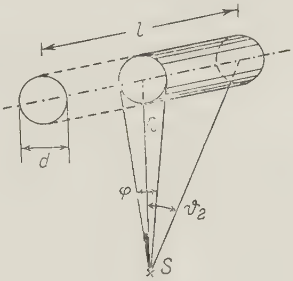

Fig. 5. Special case of a cylindrical counter

4. *Integral Representation of the Counting Rate*

The two functions $N_{\vartheta,\,\varphi}\,(r)$ and $q(\vartheta,\ \varphi)$ enter into an integral theorem for the counting rate of a big counter as follows:

$$N(\Omega) = \int\limits_{V(\Omega} N_{\vartheta,\,\varphi}\,(r) \cdot q\,(\vartheta,\,\varphi)\, r^2\, dr \cos \vartheta\, d\vartheta\, d\varphi \tag{7}$$

The integration space $V(\Omega)$ is the infinitely extended volume, which is shadowed by the counter surface (Fig. 2). With functions (1) and (6) we get approximately, for moderate angles ϑ, the integral

$$N\,(r_0, \vartheta_1, \vartheta_2) = \frac{Q}{l r_0} \int\limits_{\vartheta_1}^{\vartheta_2} e^{-\frac{\mu}{\cos \vartheta}\,(r_0 - \delta)}\, d\vartheta,\ \ Q = q_0\, N_0\, \frac{d}{4\pi}\,. \tag{8}$$

In this r_0 is the shortest distance between the axis of the counter and the gamma ray source, l the effective length and d the effective diameter of the counter. δ takes into account the distance between the ground and the axis of the counter as well as the thickness of the aluminium base plate. In practice this is taken as half the counter diameter $d/2$. With the abbreviation

$$W\,(k, \cos \vartheta) = \int\limits_0^{\vartheta} e^{-\frac{k}{\cos \vartheta}}\, d\vartheta \tag{9}$$

the geometrical dependence of the counter can be represented by a simple function of the integral (9)

$$N(r_0, \vartheta_1, \vartheta_2) = \frac{Q}{l\, r_0}\, W(\mu\,(r_0 - \delta), \cos\vartheta)\,\Big|_{\vartheta_2}^{\vartheta_1} \tag{10}$$

The integral defined in (9) represents a new transcendental function whose dependance on k and ϑ is shown in the block diagram Fig. 6. Table 1 gives values of W for integral values of k between 1 to 10 and for ϑ between 0° to 90° at intervals of 2°. The intermediate values in k can be determined by graphical interpolation on a semi logarithmic net as, to a close approximation,

$$W(k, \cos\vartheta) \approx W(k_0, \cos\vartheta)\, e^{g(\vartheta)\,(k-k_0)} \tag{11}$$

For examining the table, we utilized a relation between the complete integral $W(k, o)$ and the modified Hankel-function k_0 of degree zero (see Jahnke-Emde 1948, page 232). By substituting $t = tg\ \vartheta$, there results

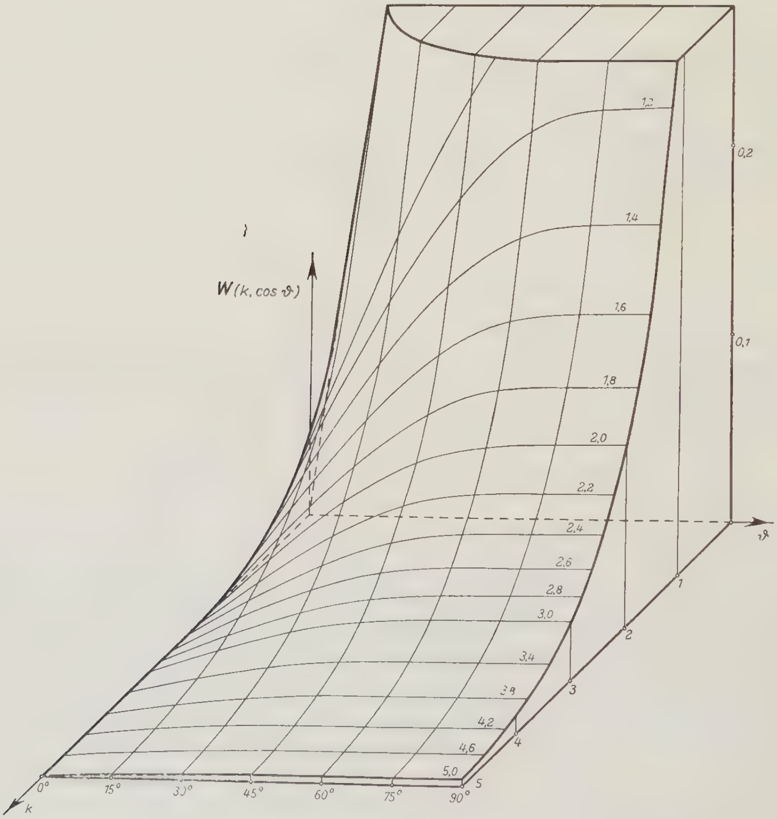

Fig. 6. Integral $W(k, \cos\vartheta)$ as a function of k and ϑ

$$W(k, o) = \int_{0}^{\infty} \frac{e^{-k\sqrt{t^2+1}}}{t^2+1}\, dt = \int_{k}^{\infty} K_0(v)\, dv \qquad (9a)$$

5. *Interpretation of Measuring Curves of Big Counters*

The integral representation (10) for the counting rate was compared with the results of several experiments. Two of these, illustrated in Fig. 7, will be discussed. We placed the aluminium base plate with the two counters on top of a container filled with sand and sawdust having a mean density of about 1,3 g/cm³. The gamma source under the container was displaced both parallel to and perpendicular to the counters. When plotting the measured points, corrections for background and, as far as necessary, for dead time were applied. The theoretical curves have been shown in both cases. The agreement between experiment and theory 1) must be regarded as satisfactory, particularly as certain variations of density values cannot always be avoided.

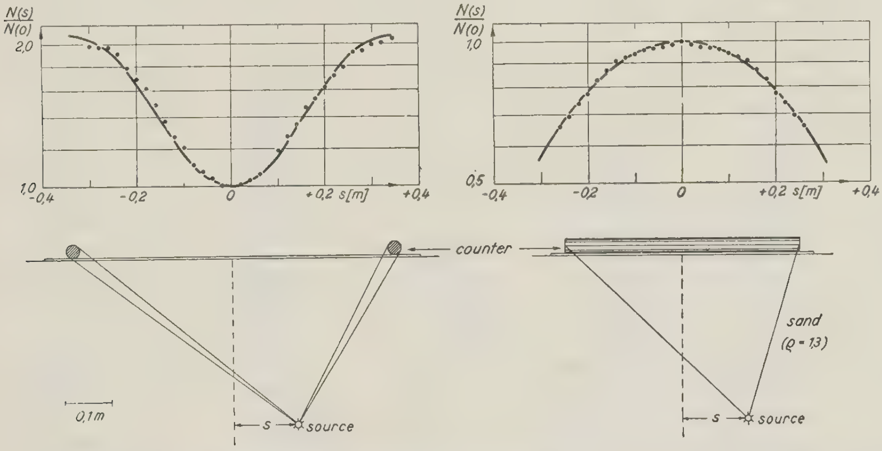

Fig. 7. Comparison of experimentical and theoretical results.—Theoretical curve derived by means of the function $W(k, \cos \vartheta)$ with $k = \mu\,(r_0 - \delta)$, $\mu = 0{,}0684$ cm^{-1}

In the next figure (Fig. 8) is shown the complete theoretical shape of a depth sounding curve on a semi logarithmic net, on which the counter effect $r_0^2\,N$ is plotted as a function of r_0 according to equation (10). An obvious curvature is apparant at small distances; in the measured range, however (between 35 and 80 cm), the curvature is so small that the measured points lie approximately on the straight line

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1) The conformity was reached with an absorption coefficient $\mu' = 1/19{,}0$ cm$^2 . g^{-1}$, which is about 3% smaller than that of the actual field density meter (comp. (4)). This difference is obviously due to the different laboratory test conditions.

Table 1.

The function $W(k, \cos\vartheta)$ in dependence on ϑ and k. (Accuracy: ± one unit of the last decimal)

ϑ \ k	1	2	3	4	5
2	0,01283	0,004721	0,001736	0,0^{3}6386	0,0^{3}2348
4	2564	9422	3466	12740	4683
6	3843	14109	5184	1903	6988
8	5115	1876	6882	2523	9252
10	6383	2337	8555	3131	11460
12	7643	2792	10198	3724	1360
14	8894	3240	1180	4299	1566
16	10134	3680	1337	4854	1763
18	1136	4111	1488	5386	1950
20	1257	4532	1634	5894	2127
22	1377	4941	1775	6375	2291
24	1494	5339	1909	6827	2444
26	1610	5723	2036	7250	2584
28	1723	6093	2156	7642	2712
30	1835	6447	2269	8002	2827
32	1943	6785	2375	8330	2929
34	2048	7107	2472	8627	3019
36	2151	7411	2562	8891	3097
38	2251	7696	2644	9124	3164
40	2347	7962	2717	9327	3220
42	2439	8209	2783	9502	3266
44	2528	8435	2840	9649	3304
46	2613	8641	2891	9772	3334
48	2698	8827	2934	9871	3357
50	2774	8993	2970	9950	3374
52	2845	9138	2999	10011	3386
54	2911	9264	3023	10056	3395
56	2973	9371	3042	10089	3401
58	3029	9460	3056	10112	3404
60	3079	9532	3067	10127	3406
62	3123	9589	3074	10137	3408
64	3162	9632	3079	10142	3408
66	3194	9663	3082	10145	3409
68	3221	9684	3083	10146	.
70	3243	9697	3084	10147	.
72	3259	9705	3085	.	.
74	3270	9709	.	.	.
76	3278	9711	.	.	.
78	3282	.	.	.	.
80	3284	.	.	.	.
82	3285	.	.	.	.
84	.	.	.	.	.
86	.	.	.	.	.
88	.	.	.	.	.
90	0,3285	0,09711	0,03085	0,010147	0,003409

$\vartheta \diagdown k$	6	7	8	9	10
2	$0{,}0^4 8637$	$0{,}0^4 3176$	$0{,}0^4 1168$	$0{,}0^5 4296$	$0{,}0^5 1580$
4	17211	6326	2325	8545	3141
6	2566	9422	3460	12697	4664
8	3392	12439	4561	1671	6132
10	4190	1535	5620	2056	7529
12	4959	1814	6628	2420	8842
14	5697	2079	7576	2759	10059
16	6397	2327	8458	3073	1117
18	7054	2558	9270	3358	1218
20	7666	2771	10009	3614	1307
22	8231	2964	1067	3841	1384
24	8746	3138	1126	4040	1451
26	9211	3293	1177	4210	1508
28	9627	3428	1221	4353	1555
30	9993	3545	1258	4472	1592
32	10312	3644	1288	4568	1623
34	1059	3727	1313	4645	1646
36	1082	3795	1334	4704	1663
38	1101	3850	1349	4749	1676
40	1116	3893	1363	4782	1685
42	1129	3926	1372	4805	1692
44	1138	3950	1378	4821	1696
46	1145	3968	1383	4832	1698
48	1151	3980	1385	4838	1700
50	1155	3989	1387	4842	1701
52	1157	3994	1388	4884	.
54	1159	3997	1389	4846	.
56	1160	3999	.	.	.
58	1160	4000	.	.	.
60	1161	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
90	0,001161	$0{,}0^3 4000$	$0{,}0^3 1389$	$0{,}0^4 4846$	$0{,}0^4 1701$

$$r_0^2 N \approx \bar{Q}\ e^{-\bar{\mu}(r_0 - \delta)},\ \bar{\mu} = \bar{\mu}' \rho \tag{12}$$

The "apparent" absorption coefficient $\bar{\mu}'$ is smaller than μ'. For the two sources, it is roughly

$$\left(\frac{1}{\bar{\mu}^1}\right)_{Co^{60}} = 19{,}0\ g \cdot \mathrm{cm}^{-2} \text{ and } \left(\frac{1}{\bar{\mu}^1}\right)_{Cs^{137}} = 15{,}4\ g \cdot \mathrm{cm}^{-2} \tag{13}$$

respectively. A theoretically predicted dependence of the "apparent" coefficient μ' on the density ρ is too small to be observed when the densities lie within the range from 1,2 to 2,5 as normally is the case in the field.

This fact facilitates the construction of calibration curves. According to Fig. 9a, the measured points of a depth sounding are plotted as counting effect $r_0^2 N$ as a function of r_0 on a semi logarithmic net, for soils of different densities, and the homogeneity of a soil is examined by fitting a straight line to the measured points. If the measured points lie on a straight line, the counting rates N can be transferred on a semi logarithmic net as a function of the density ρ and there, the points of equal source depth z of at least two different soils can be connected by a straight line (Fig. 9b). From these calibration curves we can, with the interesting depth for each counting rate, read the density of a homogeneous soil as abscissa. The calibration curves show that with this absorption method, a radiator as soft as possible (μ' large) should

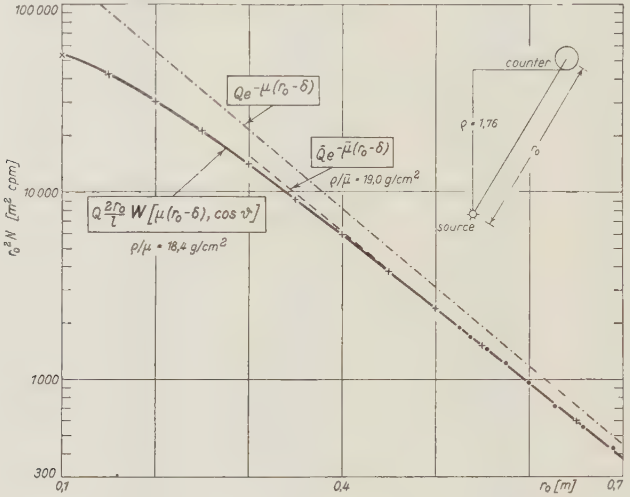

Fig. 8. Counting effect $r_0^2\ N$ as a function of the distance r_0 for a large counter

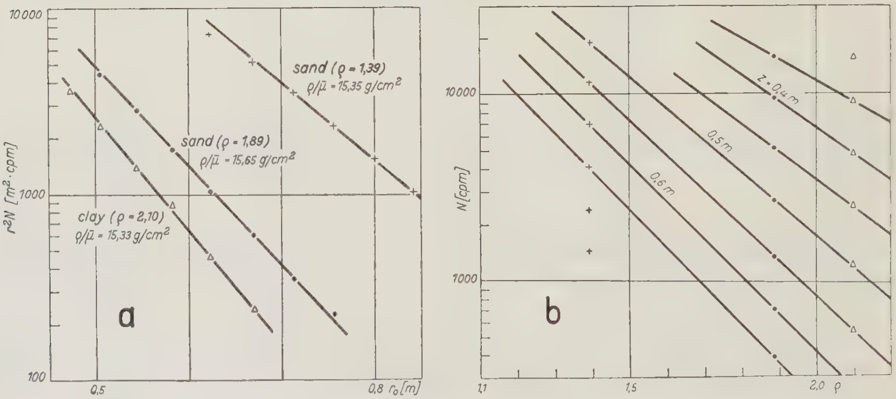

Fig. 9. *a*) Counting effect $r_0^2\ N$ as a function of the distance r_0. *b*) Counting rate N as a function of the density. (Calibration curves)

be applied, for then a large ratio of the counting rate variation to the density variation is obtained.

The great difference between the actual curve and the asymptote

$$r_0^2 \tilde{N} = Q\, e^{-\mu(r_0 - \delta)} \tag{14}$$

in Fig. 8 is understandable, if we consider that a counter of 50 cm length in a distance of 80 cm cannot be regarded as small.

6. *The Influence of Geometrical Errors*

Since an asymmetry in the position of the source (by displacement of the probe) causes errors in the measuring result, it is essential to examine the influence of such geometrical variations in the measuring arrangement. For a displacement of the probe point parallel to the counter axis (direction x in Fig. 10b), we can write

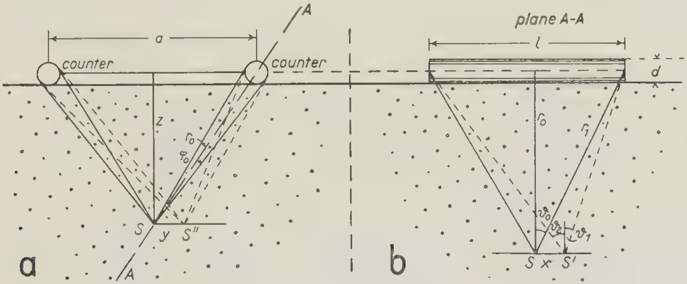

Fig. 10. Influence of geometrical errors

$$\frac{N(x)}{N(o)} = \frac{W(\mu r_0, \cos\vartheta_1) + W(\mu r_0, \cos\vartheta_2)}{2\, W(\mu r_0, \cos\vartheta_0)} \,.$$

In this formula, the shortening of the distance r_0 by the amount δ is neglected in order to simplify the calculation. By introducing the variable $z = 1/\cos\vartheta$ (compare integral (9)) and subsequent expansion around the point

$$z_0 = \frac{1}{\cos\vartheta_0} = \frac{r_1}{r_0}\,;\ (r_1^2 = r_0^2 + l^2/4)$$

one gets, after some calculation,

$$\frac{N(x)}{N(o)} = 1 - (2 + \mu r_1)\, \frac{r_0\, l}{4\, r_1^4} \, \frac{e^{-\mu r_1}}{W(\mu r_0, r_0/r_1)}\, x^2 + o\,(x^4)\,. \tag{15}$$

It is assumed here that the displacement x is not too large compared with r_0 and r_1. As can be recognized, the response of the arrangement to geometrical displacements parallely to the counter axis increases with growing density but, on the other hand, decreases with long counters.

With the bending of the probe point perpendicularly to the counter axis (in the direction y in Fig. 10a), the distance r_0 as well as the angles ϑ and φ are altered for both counters. Accordingly, the ratio of the relative counter rates can be expressed by

$$\frac{\tilde{N}(y)}{\tilde{N}(o)} = \frac{\varphi_0{}' \, W(\mu r_0{}', \cos\vartheta_0{}') + \varphi_0{}'' \, W(\mu r_0{}'', \cos\vartheta_0{}'')}{2\,\varphi_0 \, W(\mu r_0, \cos\vartheta_0)} \, .$$

Expansion as a series of the deflection y produces, as in (15), only terms in y^2, i.e.

$$\frac{\tilde{N}(y)}{\tilde{N}(o)} = 1 + B\,y^2 + o\,(y^4) \tag{16}$$

where

$$B = \frac{a^2 - 2z^2}{4\,r_0{}^4}\left(1 + \mu r_0 \,\frac{\tilde{W}_0}{W_0}\right) + \mu^2 \,\frac{a^2}{8\,r_0{}^2}\,\frac{\overset{\approx}{W}_0}{W_0} + $$
$$+ (2 + \mu r_1)\,\frac{l a^2}{16 r_1{}^2 r_0}\left(\frac{1}{r_0{}^2} + \frac{1}{r_1{}^2}\right)\frac{e^{-\mu r_1}}{W_0} - \frac{l\,z^2}{4\,r_1{}^2\,r_0{}^3}\cdot\frac{e^{-\mu r_1}}{W_0}\,, \tag{16a}$$

and

$$W_0 = W(\mu\,r_0, \cos\vartheta_0), \tilde{W}_0 = -\frac{\delta}{\delta k}\,W(k, \cos\vartheta_0)_{k=\mu r_0}, \overset{\approx}{W}_0 = \frac{\delta^2}{\delta k^2}\,W(k, \cos\vartheta_0)_{k=\mu r_0} \tag{16b}$$

The second term of the sum in B is of greatest importance. Consequently, the change resulting from a deflection of the probe perpendicularly to the counter axis becomes greater as the density increases and as the ratio of counter separation to source distance (a/r_0) becomes larger.

Example: A relative error in the counting rate of 1% is obtained if, in a soil of density 1,7 g/cm^2, the radiation source at about 50 cm depth is displaced by about x = 4,0 cm or about y = 2,3 cm (Exact values: z^2 = 2375 cm^2 at r_0 = 60 cm, r_1 = 65 cm, l = 50 cm, a = 70 cm, $1/\mu'$ = 18,4 g/cm^2. We computed for the arguments k = 72/13 and ϑ_0 = 0,4 the values W = 0,001 3615, $\tilde{W}$ = 0,001 3947, $\overset{\approx}{W}$ = 0,001 4296).

Compared with a displacement of the radiation source parallel to the counter axis, the arrangement is only half as sensitive for displacements perpendicular to the counter axis. The absolute errors are surprizingly low. The reason lies in the symmetry of the counter arrangement, which finds its mathematical expression in the fact that only square terms occur in the expansions in x and y.

7. *Density Variations with the Depth*

From the integral expression (10) we can determine the influence of a variation of the density with the depth. This results in a method by which the density values of individual layers can be determined.

The counting effect in the case of several layers is

$$r_0^2 N = Q \frac{4 r_0}{l} W(\mu' \bar{\rho}(r_0 - \delta), \cos \vartheta_0) \tag{17}$$

with $\cos \vartheta_0 = r_0 / r_1$ and

$$\bar{\rho}(r_0 - \delta) = \rho_1 r_0^{(1)} + \rho_2 r_0^{(2)} + \ldots \tag{17a}$$

Fig. 11 shows three computed examples. In curve 1 we have homogeneous sand of the density 1,75. With curve 2, the sand in underlain, in 25 cm depth, by soil of the density 1,9. With curve 3, we additionally assume a third layer at a depth of 50 cm with the density 2,1. When crossing the interfaces, one obtains an abrupt change in slope of the curve. The accurate determination of the location of the break is of greatest practical importance for determining the density of the underlying layer.

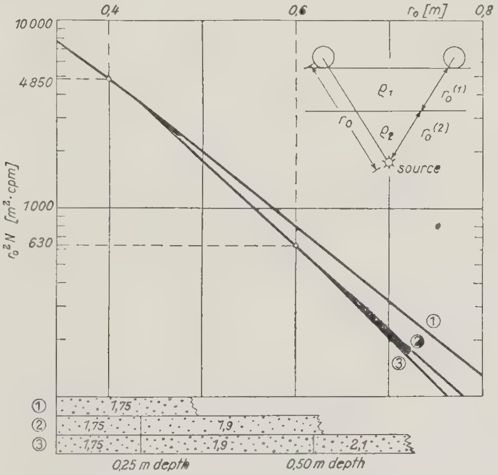

Fig. 11. Variation in density with the depth

For finding out the density of the second layer, we proceed to determine, first of all, the mean density of the irradiated soil either by means of the set of calibration curves, or by the integral values using two measured points. From this we compute ρ_2 according to formula (17a) by using the known density ρ_1 and the two parts of r_0 i.e. $r_0^{(1)}$ and $r_0^{(2)}$.

Example: (see Fig. 11) From the known density $\rho_1 = 1{,}75$ g/cm³ and the portions $r_0^{(1)} = 30{,}9$ cm and $r_0^{(2)} = 27{,}6$ cm results from

$$W(\mu' \bar{\rho} (r_0 - \delta), \cos \vartheta_0) = \frac{630}{4840} \cdot \frac{4}{6} \cdot 0{,}0121 = 0{,}0105$$

with the argument $\vartheta_0 = 22° \, 35'$ the second argument

$$\mu' \bar{\rho} (r_0 - \delta) = 5{,}77,$$

and with $\delta = 1{,}5$ cm and $1/\mu' = 18{,}4$ g/cm² results

$$\rho_2 = \bar{\rho} \frac{r_0 - \delta}{r_0^{(2)}} - \rho_1 \frac{r_0^{(1)}}{r_0^{(2)}} = 1{,}89 \text{ g/cm}^3$$

A pronounced density variation in the depth works out as a considerable variation in the counting rate. For an estimation we compute the relative variation in the counting rate which occurs if the probe tip, with a distance $r_0 - r_0^{(2)}$ of the counters, penetrates soil of density ρ_2 (counting rate N) instead of ρ_1 (counting rate $\overline{N}$).

According to (8) this is

$$r_0^2 (\overline{N} - N) = Q \, \frac{4 r_0}{l} \int_0^{\vartheta_0} \left(e^{-\frac{\mu' \rho_1 \bar{r}_0}{\cos \vartheta}} - e^{-\frac{\mu'}{\cos \vartheta} (\rho_1 r_0^{(1)} + \rho_2 r_0^{(2)})} \right) d\vartheta \tag{18}$$

$(r_0^{(1)} + r_0^{(2)} = \bar{r}_0)$. If we remove the exponential factor from the term in brackets in the subjectof integration and then expand the remaining factor we obtain, by using the integral $\tilde{W}(k, \cos \vartheta)$ introduced in (16b), for the relative counter variation the expression

$$\frac{\overline{N} - N}{N} = \mu' (\rho_2 - \rho_1) \, r_0^{(2)} \, \frac{\tilde{W}(\mu' \rho_1 \bar{r}; r_0/r_1)}{W(\mu' \rho \, \bar{r}_0; r_0/r_1)} \tag{19}$$

Example: For the purpose of attaining a measurable effect of 2%, a distance of irradiation $r_0^{(2)}$ of less than 1 cm suffices if we assume a density change from 1,7 to 2,2 and a distance to the counter of $r_0 = 60$ cm. (Exact value: 0,72 cm at $1/\mu' = 18{,}4$ g/cm²). We can derive from this that jumps in the measured graph are mostly due to gravel intercalations in the sands, which lie immediately in front of the radiation source.

Appendix: The Component of Scattering in the Gamma Radiation

In order to be able to estimate the component of gamma quanta which, with the absorption method, reach the counter by scattering and thereby cause an incoherence, the following test was effected.

A flat pencil of gamma rays (Co^{60}) of 0.2 mm width, sharply defined with lead plates continuing over a distance of about 20 cm, inpinges from below on a plastic container (2 mm wall thickness, 70 cm long, 30 cm wide and 35 cm high). The thickness of the lead protection is such that the component of the radiation penetrating the lead is negligibly small. To make possible point-by-point measurements in this case without alteration of the density, we used water as an absorbing agent. With a micro counter we measured, over horizontal planes at different level with the counter parallel to the gap, the intensity point-by-point and corrected as far as possible for the dead time. Altogether we measured approximately 350 points of the half space (Figs. 12 and 13).

Clearly perceptible in both figures is the course of the primary ray,

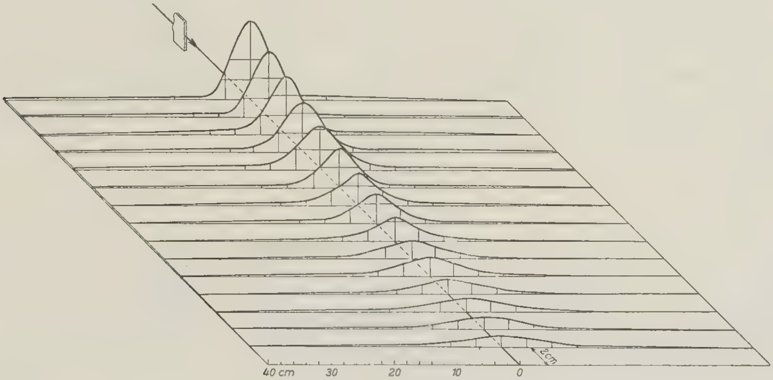

Fig. 12. Scattering of a diaphragmed ray in water (perspective view)

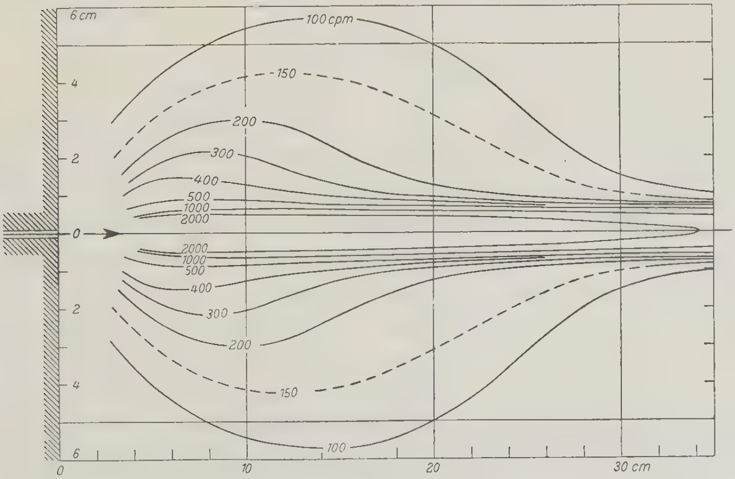

Fig. 13. Scattering of a diaphragmed ray in water (diagram of isorates)

which along its whole length has a sharply defined boundary with the scattering space, even after it has penetrated a relatively large layer of matter. The curves perpendicularly to the irradiation way (Fig. 12) have the character of bell-shaped curves. With increasing depth penetration of the ray, they show a decrease in maximum, which is to be expected due to the absorption, and also a slight extension of the half-width. If the bell-shaped curves were solely due to the divergence of the bunch of rays, they should be Gaussian curves. The measured intensity far outside the primary ray (about from 10 cm off the centre line), however, is noticeably greater than can be expected from the exponential slope of a Gaussian curve. In these outer regions of the bell-shaped curves, therefore, the intensity originates mainly from scattered gamma-quanta. If, therefore, we prolong the outer parts of the bell shaped curves i.e. the parts not influenced by the primary ray, towards the centre, we get a value in the centre which is, 1/10 of the measured one. That means that about 9/10 of the counting rates in the primary ray are caused by unscattered quanta. The coherence of the radiation in the absorption methods is therefore well established.

CONCLUSIONS

The above method of determining the density by gamma absorption is a suitable means of finding the density of near-surface layers quicker and more accurately than is possible by taking samples. The simple handling of the method and the size of the counters, which need not necessarily be limited by the equipment, result in fewer sources of error and in a good consistency of measured values which is, for instance, not always attainable with drilling methods where smaller counters have to be used. The symmetry in the arrangement of the counters takes care of an averaging of geometrical errors. The soil can be investigated down to depths of 80 to 100 cm, which is sufficient for many purposes. Thus, on construction sites the fillings are being applied in layers and each separate layer is consolidated individually.

The accuracy of the density values in homogeneous fillings can be estimated with ± 1%. Table 2 gives an example in which isotope measurements are compared with laboratory measurements at 20 measuring places. Each value in the columns 2 and 3 represents the arithmetic mean of several determinations. Column 4 shows the variation width of the isotope measurement, which remains below 5% throughout. The deviations of the mean values of columns 2 and 3 from each other lie, with one exception at and below 1%. With inhomogeneous fillings the error, when stating the density, is bigger and depends mainly on the accuracy with which the interfaces can be recognized.

The demonstrated theoretical dependence of the counting rate upon the position of the radiation source serves as a preliminary investigation for

Table 2. Density measurements (Düsseldorf 1955) on the suggestion of the "Forschungsgesellschaft für das Strassenwesen e. V., Köln", working committee for filling cable trenchies (Dr. Goerner)

1 Measuring Point No	2 Density of moist places (taking of samples) ρ_s	3 Density of moist places (isotope measurement) ρ_i	4 Variation Width in % of ρ_i	5 Deviation from ρ_s in percents compared to ρ_i
1	1,532	1,516	3,2	— 1,0
2	1,708	1,705	0,5	— 0,18
3	1,683	1,697	2,3	+ 0,83
4	1,670	1,668	0,6	— 0,12
5	1,712	1,706	2,3	— 0,35
6	1,656	1,648	1,2	— 0,48
7	1,681	1,683	2,3	+ 0,12
8	1,892	1,901	4,1	+ 0,48
9	1,914	1,904	3,6	— 0,52
10	1,888	1,894	0,5	+ 0,32
11	1,881	1,882	2,0	+ 0,53
12	1,871	1,885	4,7	+ 0,75
13	1,894	1,897	3,6	+ 0,16
14	1,884	1,887	2,6	+ 0,16
15	1,895	1,859	4,2	— 1,9
16	1,921	1,933	2,6	+ 0,62
17	1,915	1,918	1,0	+ 0,16
18	1,590	1,592	4,3	+ 0,13
19	1,910	1,920	1,5	+ 0,52
20	1,875	1,865	4,7	— 0,53

treating more complicated problems, as they occur, for instance, in scattering methods. These methods, as is generally known, are applied not only to problems concerning engineering research, but, more recently, to drillings for crude oil, too.

ACKNOWLEDGMENTS

The authors are indepted to Mr. I. Wendt for his interest in the subject of this paper, and also for his permission to use several older experimental results (Fig. 9 and Table 2 which were obtained by him and Mr. E. Beer). Miss U. Wehmer has rendered good assistance by calculating Table 1.

The authors wish also to thank their colleagues in the Amt für Bodenforschung for their remarks and criticism, in particular Mr. H. Flathe and Mr. H. Nielsen for their critical revision of the manuscript.

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SOME PROBLEMS OF THE AEROMAGNETIC SURVEYS [1])

BY

W. DOMZALSKI

Abstract

A brief description of the procedure usually adopted for ascertaining the accuracy o aeromagnetic data is given as a background to the discussion of factors which affect this accuracy. These factors fall mainly into two groups: spatial positioning, i.e. relation to the ground surface, and effects contributing to the observed relative magnetic values. The evaluation of the observed anomalies in terms of the most probable causes and the anomalies themselves are directly influenced by the amount of the available control of factors mentioned above. The effects of various factors, such as plan positioning, height keeping, diurnal drift, are discussed, the arguments being based on theoretical and practical premises.

I. Introduction

1. The purpose of the paper is to discuss various factors affecting aeromagnetic observations and their evaluation. The aeromagnetic survey permits a rapid accumulation of very useful data which, however, can be misused unless a correct approach is made. This can only be done if the inherent limitations of the method are appreciated.

2. An airborne survey can be either a reconnaissance survey or a detailed one, depending on the circumstances. It is usually possible to plan a survey to fit given requirements, although sometimes, due to specific local conditions, the survey will fall automatically in another class and a different approach may result in the misuse of data.

II. Preliminary Considerations

A. The aeromagnetic record represents relative variations in the magnetic field, usually in the total field.

The observed variations depend upon a number of factors which are listed below:

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[1]) Part of a paper presented at the Twelfth Meeting of the European Association of Exploration Geophysicists, held in Brussels, 5 - 7 June 1957.

(i) Position of the aircraft relative to the ground surface.
  (a) Plan position.
  (b) Altitude.
  (c) Direction of flight.
(ii) Characteristics of a disturbing body.
  (a) Shape.
  (b) Size.
  (c) Susceptibility contrast.
  (d) Attitude in relation to the magnetic north.
  (e) Attitude in relation to the ground surface.
  (f) Depth below the surface.
  (g) Remanent magnetisation.
(iii) Magnetic characteristics of the area.
  (a) Magnetic inclination.
  (b) Field strength.
  (c) Normal gradient.
  (d) Time variations of the magnetic field.
(iv) Recording system.

These factors will be considered in a somewhat different order, being grouped in a manner related to the sequence of events occurring during an aeromagnetic survey.

A short recapitulation at this stage of standard procedures will provide a background to the discussion which follows.

B. The position of the aircraft is determined from the indication of an altimeter and from a system which enables the location of the aircraft in plan.

(1) The altimeter can be either of the barometric type, depending on the change of pressure with altitude, or it can be a radio altimeter registering a short wave signal reflected from the ground surface.

(2) The plan positioning can be achieved by navigational fixes and at the instant of estimating the position of the aircraft in relation to a landmark (natural or artificial) the magnetic record is annotated appropriately, taking photographs continuously with a vertical camera and referring the photograph numbers to the magnetic record by a fiducial system, or employing a radio-location system.

In each method the instantaneous position of the aircraft is related to a base map which may take the form of a topographical map, a photo-mosaic or a co-ordinate map of the radio-location system.

C. The magnetic record reflects variations of the magnetic field which are a function of spatial position and time. From the point of view of exploration geophysics the required variation is that which is a function of the plan position.

It is essential, therefore, to eliminate variations due to altitude changes and the time variations. The former are reduced to a minimum by maintaining a constant altitude as closely as possible, either in relation to sea level or to the ground surface, depending on the type of the survey. Time variations cannot be excluded and must be either determined or spread evenly with all other discrepancies by a system of adjustment.

III. Problems of Positioning

The accuracy of positioning depends on several factors.

A. *Plan positioning*

1) The accuracy of plan positioning will depend on the method used, availability of ground detail, plotting accuracy, the accuracy of the base map, constancy of the ground speed of the aircraft and, on occasions, the correct estimate of the ground speed of the aircraft.

The plotting accuracy and the accuracy of the base maps will affect the positioning of the aircraft in the same way as they affect the positioning of any ground survey. In the ground operations, however, it is possible and frequently done to build a well co-ordinated local reference system by running a transit or a plane table survey. In an airborne survey, however, due to the speed of operations and vast areas covered, it is necessary to make use of existing maps or of photo-mosaics, unless a radio-location system is used.

2) Of the possible methods of fixing the aircraft position in plan, visual fixing is impracticable for accurate results and suitable only as a general guide to the aircraft position.

(3) In general, the flight pattern is either a rectangular grid whose mesh is determined by a number of considerations or a series of parallel lines connected by reference points at the extremities of lines.

If sufficient ground detail is available, it is possible to recognize the points of intersection on the positioning film and thus ensure that the intersections are magnetically tied (assuming no altitude difference). Unless, however, good maps exist this procedure does not ensure the correct location in relation to the ground. This can only be achieved if the detail on the positioning film can be recognized on the map.

In either case, however, the track of the aircraft on the ground has to be interpolated between the recognized and plotted points. This interpolation is based on the assumption that the ground speed of the aircraft remained constant over the interpolated interval.

4) To improve accuracy it is necessary to increase the amount of positions recognised on the map and thus shorten the interval over which the interpolation is carried out. This however, apart from the economic considerations of

time involved, is a function of the amount of ground detail available for recognition. Another factor which enters at this stage is the accuracy of the map. If the distance between two recognised points on the map differs from the true distance, a distortion is introduced.

In a statistically investigated case the variation of the average speed was of the order of 5%, this determination being based on 20 kms. intervals between points well identified on the map.

Variations in the speed of the aircraft are not instantaneous when aircraft flies on a steady course. It is reasonable to assume that the variation of the true speed over an interval of this order is of the same magnitude as variation of the average speed over different intervals. If this variation is assumed to be approximately linear over a comparatively short interval, the magnitude of the error in the determination of a position of a point in an interval between two identified points could be of the order of 100 metres at an average aircraft speed of 200 km. per hour.

Other factors to be considered are the accuracy of the determination of the centre point of the photo-frame in relation to the ground and the verticality of the camera at the moment of exposure.

If aircraft flies at an altitude of 150 metres then, with a camera of focal distance of 30 mm., the scale of the photograph is 1 : 5,000. The position of the centre point in relation to the ground detail can easily be determined to within 2 millimetres which, at this scale, is equivalent to 10 metres on the ground.

The range of scales on which the results are presented usually falls within certain limits, the largest scale likely to be adopted being 1 : 25,000. On such a scale 1 millimetre is equivalent to 25 metres. The estimate of the position of the centre point of the photograph in relation to ground detail is, therefore, of a higher accuracy than the accuracy of plotting on a scale suitable for a detailed survey. At 150 m., a deflection of the camera axis of 1° from the vertical would result in about 2.5 metres displacement on the ground. Under average conditions, therefore, this is a negligible error.

The situation changes substantially, however, if due to the lack of ground detail, the position of the aircraft can be related to the ground only at a few widely spaced points, or if there is a lack of identifiable surface detail over a large area. Under such circumstances the uncertainty due to the variations in the aircraft speed and course may lead to large errors, particularly if inaccurate maps on a small scale have to be used.

Nevertheless, it is necessary to bear in mind the scale of the problem. In the case of a large scale survey in which considerable inaccuracies in positioning might arise due to the lack of the ground detail, the importance of pin-pointing does not arise to the same extent because other factors, such as line spacing, determine the reconnaissance character of the survey.

When a radio-location system is used, the accuracy of positioning depends on the system used, the area considered in relation to the transmitting stations, i.e. angle of intersection of the grid, the accuracy of the known corrections to the system, and finally atmospheric conditions (static electricity, etc.).

From experience, this accuracy under normal conditions is of the order of 100 metres.

B. *Constancy of Altitude*

Depending on the type of survey, i.e. the pre-arranged altitude of flying, the height indication is obtained from either a barometric or a radio altimeter.

1) *Constant barometric flying*

In this type of survey the height is maintained by means of the barometric altimeter. To evaluate the relationship between the true altitude above the sea level and the indicated altitude it is necessary to consider the following factors:

(i) The accuracy with which the indicated altitude can be read off the instrument dial. This can be taken as ± 3 metres.

(ii) The accuracy of the instrument, i.e. how closely the indicated altitude approaches the altitude corresponding to the ambient pressure. This factor depends on the mechanical characteristics of the instrument and is usually given in manufacturer's specification.

(iii) The atmospheric conditions. The barometric altimeter gives an indication proportional to the ambient pressure. The pressure is a function of altitude and there exists theoretically a normal pressure gradient. However, the ambient pressure at a given altitude does not conform necessarily to this theoretical value, but is affected by meteorological conditions, such as temperature, humidity and local atmospheric highs or lows.

The normal gradient varies with altitude and for a range of 700 metres to 1,000 metres is about one millibar per 9 metres (30 feet) (1 millibar $= 10^3$ dynes/cm^2).

It will be appreciated that along a flight line of, say, 200 kms there may exist variations of the order of several millibars. Even if the meteorological information is available in the form of a pressure gradient along the line of flight, this is inherently an approximate and average value, from which local departures will occur. In one test the barometric pressure changed by about 1.5 millibars in one hour. The indications from the barometric altimeter were 5% to 20% too low at a height varying from 300 metres to 150 metres respectively. It may reasonably be expected that at those altitudes at which the barometric altimeter would be used as an indicator, the percentage error would be of a lesser order.

It would be of little value to estimate the discrepancies due to variable atmospheric conditions, since these depend on the area of operations and the prevailing conditions at the time. Nevertheless, it will be useful to quote the order of overall discrepancies encountered in practice. Such an estimate is only possible over the intersections and is based on the comparison of the scale of the 35 mm. positioning film, on which it is necessary to have at least two identifiable points appearing on each frame.

The distance between them can be measured to within 0.001 millimeters by use of an optical vernier instrument. Such an accuracy would be incompatible with other factors involved (dimensions of pin-point, resolution of film grain) and measurements to 0.01 millimetres are sufficient. It is also necessary to know the approximate height of the plane above the ground, but this can be obtained from the radio altimeter record.

The discrepancies in altitude over the intersections varied from 0 to ± 70 (± 20) metres. The figure in brackets denotes the accuracy of the determination of the first figure. The figures quoted are averages for altitudes of the order of 1,000 metres above sea level.

2) *Flying at a constant distance above the ground surface*

This type of survey, usually flown at about 150 metres above the ground surface, depends on the indication obtained from the radio altimeter.

Controlled experiments were carried out in order to check the accuracy of the indication given by the radio altimeter. The control was by two independent photogrammetric methods. At an altitude of 150 meters the radio altimeter error was of the order of 5%, and remained the same at an altitude of 300 meters. In both cases the radio altimeter indication was too low.

C. *Effects of positioning and altitude errors*

It is difficult to evaluate the magnitude of error in gammas which can occur due to errors of positioning and altitude variations.

1) As regards the former, the error will depend almost entirely on the horizontal magnetic gradient in the locality. One reassuring consideration is that in large scale surveys flown at high altitudes, usually oil surveys, the gradient of the observed field is less than in mineral surveys flown at comparatively low altitudes. Thus, when the error of positioning may be great, the horizontal magnetic gradient is usually small. If the latter is large, as it may be in a mineral survey, then the control of positioning is better.

It must be remembered that if a survey is flown on a grid and the intersections are found the distortion is unlikely to occur if the maps are fairly accurate. On the other hand, if the maps are not accurate and the intersections cannot be identified larger errors are possible.

2) The error due to altitude variations is a function of the vertical gradient. As a first approximation, assuming that the field is due to a dipole at the centre of the earth, it is possible to calculate the vertical gradient which is given by $3\,F/r$, where r = radius of the earth and F = total field.

On these assumptions the gradient would be approximately 2.0 gammas per 100 metres for middle latitudes. This is too small a quantity to cause an appreciable error. Some experiments, however, which have been carried out (Maple and Bowen 1951, Cahill and Van Allen 1956) show that it is necessary to assume dipole surface anomalies to account for the field of the earth. The experimental gradient was of the order of 2.5 gammas per 100 metres within the first 20 km. above the surface of the earth. Moreover this gradient will be larger for the altitude at which a survey would take place, while the experiments were concerned rather with altitudes of the order of tens of kilometres.

In an area of anomalous gradient the figures may be substantially bigger. Thus a gabbro intrusion just below the surface, approximating to a vertical cylinder of the radius of 500 metres and with a susceptibility contrast of $3{,}000 \times 10^{-6}$ c.g.s. units would give rise to a gradient of approximately 20 gammas per 100 metres on the axis of the body at an altitude of 1,000 metres.

An infinite variety of combinations is possible, but the point to be borne in mind is that under certain circumstances, the altitude errors may give rise to appreciable discrepancies.

D. *Conclusions regarding effects of positioning and altitude errors*

It appears that there will exist inherent discrepancies in the results of an aeromagnetic survey due to positioning and altitude errors. These discrepancies can be made sufficiently small so that they do not affect the results appreciably. This is achieved by proper planning and the control of the survey. Under certain conditions, however, due to the lack of adequate maps and recognizable surface detail, the errors may reach appreciable magnitude. Under such circumstances the survey should be regarded as a reconnaissance and it would be a serious mistake to try to derive detail information from a survey which, a priori, has been of a reconnaissance nature.

Obviously, in any type of survey the lines along which the information has been obtained, i.e. flight lines, must be shown as this gives a clear idea of the interpolation involved. It also permits an assessment of how much information was available for positioning the lines, apart from being a document of how close the execution followed specifications.

The effect of the spacing of the lines on the final picture obtained is not discussed in this paper as it does not come directly within its scope. An interesting communication on this subject (Agocs 1955) has already been published.

IV. PROBLEMS ARISING FROM THE NATURE OF THE MEASUREMENTS

1) *Recording system*

It may be useful to discuss shortly the accuracy of the relative measurements which are a function of the recording system. The factors affecting this accuracy can be shortly listed as follows:

(i) Ability of the system to measure the true difference in field between two points. The record can usually be read to about ± 2 gammas, and, although the measured difference should be independent of the range of measurement, an estimated accuracy of $\frac{1}{2}\%$ of the measured difference is a useful guide.

(ii) Temperature effects on the fluxgate are of the order of one gamma per degree Centigrade.

(iii) Instrument drift may vary slightly but is of small order and can be adequately controlled and evaluated.

These factors may cause errors which, under adverse circumstances, can accumulate to a noticeable magnitude, appearing for example as closure errors in a grid controlled pattern of flying. Nevertheless they will not significantly affect the results.

(iv) Consideration has to be given also to the possible misalignment of the fluxgate with the direction of the total field. Such error is equal to $F \times \delta^2/_2$, where F is the field and δ the misalignment. To achieve the accuracy of, say, 2 gammas in a field 30,000 gammas, an alignment must be within 55 minutes of arc. This is normally well within the possibilities of the instrument.

As a matter of interest it is well to note that for a vertical magnetometer the error in misalignment is $F \cos I\delta$, where I is the inclination. For $I = 30°$ and under similar assumptions as those made, to achieve an accuracy of 2 gammas, the misalignment would have to be less than 15 seconds of arc. This cannot be achieved in practice and, consequently, the total force magnetometer is more accurate.

2) *Variations of the magnetic field which are a function of time*

Two types of variations which fall into this group will affect the observations, viz. diurnal variations and magnetic disturbances.

(i) The problem of evaluation of the diurnal variations is somewhat different in an airborne survey than in that on the ground. The maintenance of the ground instrument in order to correct the aeromagnetic record can only be justified in a survey of limited extent and flown at a low altitude with the ground instrument placed centrally within the area.

When a large area is covered the indications of the ground magnetometer cannot be used for such a purpose because the pattern of the diurnal variations is a function of geographical (geomagnetic) position.

If a large area is surveyed particularly over an inaccessible territory such as desert, jungle, etc., it would not be possible to place the ground instrument at different locations where its indications could be considered in relation to aeromagnetic results.

Some investigations of the daily variations have been made and the graphs on fig. 1 are given as an example. They show the comparison of the monthly means of hourly values for January 1957 recorded at Elstree, near London (laboratories of Hunting Geophysics Ltd.) and at Istanbul Observatory. A difference of 10 gammas in the hourly variations is quite apparent, together with the displacement of characteristic parts of the curve. It must be borne in mind that these are monthly means and that differences between the daily values will be larger. In order to compare the recording of the total field magnetometer, the values of the horizontal and vertical component supplied by the observatory had been compiled.

In addition, there is some evidence (H. Aurand) that meteorological factors in a given area can affect the instrumental indications through influence of fields due to variable static charges or electrically charged particles in motion. This may cause a different variation on the surface and at the flying altitude of, say, 1,000 metres.

In consequence of these factors, the diurnal variations have to be taken into account by different means, for which an allowance is made in the flight pattern.

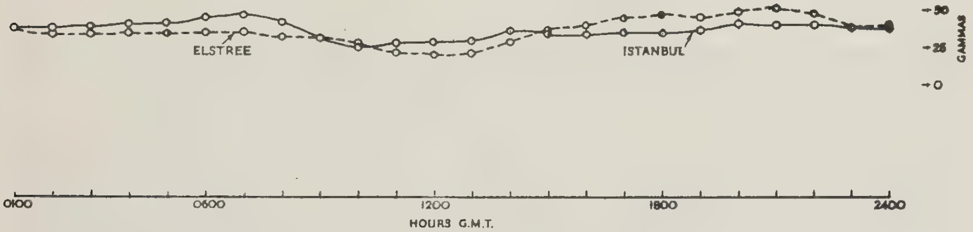

Fig. 1 Total field diurnal variation (monthly mean of hourly values) January 1957.

(ii) The problem of magnetic disturbances has to be considered very seriously whenever an aeromagnetic survey is in progress. An early warning is necessary if a magnetic disturbance occurs. The classification of the magnetic disturbances can be found in many publications, but statements concerning the effective range are somewhat vague. Information from the magnetic observatory nearest to the surveyed area should give an adequate indication. Further co-ordinated investigations are necessary to determine the critical range for a given type of disturbance as well as the magnitude which variations can attain on days of increased magnetic activity and which does not necessarily reach the magnitude of a storm, or even a bay.

(iii) The variations of the magnetic field as a function of time thus present serious problems. These problems would seem to provide a field of investigation in which it should be possible to achieve the collaboration of different organisations, without disclosing what is regarded as confidential. It concerns the exchange of data on magnetic diurnal variations and disturbances to the extent in which they may affect the observations. Specific information is required about (a) variations in the pattern of diurnal curves in widely spaced localities, (b) range of different types of magnetic disturbances. The obvious suggestion is to obtain this information partially from the Magnetic Observatories. It is surprising, however, how difficult such a task proves to be in practice. It is hoped that an organized approach directed by a scientific and professional association would cause a better response. At the same time it should be possible to collect the information from other sources and present it in a published form for a specific purpose of applied geophysics.

3) *The Regional Variation of the magnetic field.*

The corrected, or adjusted, relative measurements represent the variations in the total magnetic field which are due to a variety of causes. In exploration geophysics, anomalies of local character are the main interest. The term local may be somewhat ambiguous because it will depend on the purpose and scale of the survey. In a detailed mineral survey an anomaly of interest will generally have much smaller horizontal dimensions than an anomaly due to a large basement uplift and considered local in an oil survey. Consequently the definition of the regional variation will be somewhat flexible.

In general, the regional variation will be composed of the so-called normal variation which is a function of the pattern of the magnetic field of the Earth and of the variation due to relatively deep regional geological structure. The latter effect has to be considered in relation to the scope of the survey. Thus, in a mineral survey, the anomalies due to near surface mineralisation or basic rocks will be superimposed on the effect due to varying configuration of the crystalline basement, or causes at some intermediate depths. In an oil survey the anomalies due to comparatively local variations of the basement configuration or lithology can be superimposed on the general trend due to the attitude or nature of the basement considered over a large area. It is virtually impossible to discriminate between the two components and their effect is generally considered together.

There is a great variety of analytical and graphical methods available for the evaluation of the regional gradient. Because, however, there is an inherent flexibility in the definition, no method has a particular advantage over the other. In general, a more realistic approach is to evaluate the regional gradient from the survey data, rather than to rely on a tabulated or map presentation of the normal variation of the field of the earth. The latter has been evolved from comparatively few observations, involves uncertainty due to interpolation and does not allow for differential secular variations.

Perhaps the most reasonable approach when considering individual anomalies would be to try and use the best fitting local background as the regional function.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to Hunting Geophysics, Ltd. for permission to publish this paper, and for the data contained in it.

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BRUCKSHAW, J. McG., Private communications.

CAHILL, L. J. and J. A. VAN ALLEN, 1956, High Altitude Measurements of the Earth's Magnetic Field with a Proton Precession Magnetometer, Journal of Geophysical Research, Vol. 61, No. 3, p. 547.

MAPLE, J. E. and W. A. BOWEN, 1951, Evidence for Ionosphere currents from Rocket Experiments near the Geomagnetic Equator, Journal of Geophysical Research, Vol. 56, No. 2, p. 265.

BOOK REVIEW

Gedenkboek F. A. Vening Meinesz, Verhandelingen van het Koninklijk Nederlandsch Geologisch-Mijnbouwkundig Genootschap, Geologische Serie, Vol. XVIII, May, 1957.

As its title indicates, this volume is a special publication, compiled and published on the occasion of the seventieth birthday of Felix Andries Vening Meinesz. In addition to the efforts of the Honorary Committee, who organized the work, and the Editor, A. van Weelden, the appearance of this volume owes much to the enthusiasm of his friends and the financial assistance rendered by them and many companies both in the Netherlands and Overseas. Again, it is pleasant to note that the great popularity and fame of Professor Vening Meinesz lead to an immediate response for contributions and volunteers for those other tasks essential for the production of a commemorative volume

From the point of view of posterity, probably the most interesting part of the book is contained in the first 55 pages, for these are devoted to a brief history of the life and work of this distinguished geophysicist and, of particular interest, to personal appreciations both as a scientist and as a man. All students of geophysics meet the major scientific advances which Vening Meinesz has made to the subject but the less spectacular and far more arduous contributions in the form of organization, administration and the promotion of international cooperation in the subject tend to be overlooked. Accordingly, it is appropriate that these aspects have received the attention they deserve.

The scientific contributors to this volume make an imposing list of well-known geophysicists drawn from all parts of the world and the content of the papers cover many branches of geophysics. Not unnaturally, in view of the important advances made by Vening Meinesz in it, more than half the number are devoted to the study of the earth's gravitational field. Many phases, from instrumental considerations, geodetic applications, geophysical interpretations, etc. are covered, but two of these papers must be especially gratifying to Vening Meinesz. These virtually represent some of the latest observations in fields in which he made the first measurements of improved accuracy. One of these by Ewing, Worzel and Shurbet is a record of gravity surveys carried out in 5 U.S. Submarines using a Vening Meinesz pendulum apparatus and containing approximately 600 gravity observations. The second, by van Weelden, is the history of gravity observations in the Netherlands initiated by Vening Meinesz in the year 1913-21, and is accompanied by a map of scale 1 : 500,000 showing gravity contours at 2 mgal intervals. Other geophysical topics relate to the density distribution within the earth, convection currents in the mantle, the energy release and mechanism of earthquakes. Oceanography is represented by the temperature distribution in the deep basins off Indonesia, by a contribution on turbidity currents, and by sedimentation in rectangular basins. Finally, articles on meteorology, radioactivity and petrology are included.

As the occasion merits, and as would be expected from the international reputation of the contributors, a very high standard of excellence is maintained throughout the volume. English is the usual language but a few articles are in Dutch, French and German. The production, which is clearly printed and contains, on the whole, good diagrams has been carefully edited and only a few minor typographical errors were noted. It can be recommended, not only as a contribution to the subject, but also as an historical document.

J. M. B

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

424. *Geophysical Exploration in Alaska.*
H. K. Joesting, Arctic, Vol. 7, Nos. 3-4, pp. 165-175, 1954 (1955).
A review of geophysical surveys, including: permafrost, geothermal studies, oil, ores, radioactive minerals, and volcanology.

425. *Ten Years of Investigations at the Scientific Research Institute of Geophysical Methods of Exploration,* 1944-54.
V. V. Fedynskiy, Prikladnaya Geofiz., Vol. 12, pp. 3-30, 1955.
A brief history of the institute is followed by a bibliography of papers published by members of its staff.

426. *Computers for the Petroleum Industry.*
Petroleum, Vol. 20, No. 1, pp. 21-25, Jan. 1957.
At a meeting held recently in London by the Institute of Petroleum the following papers, dealing with computers and their application to the petroleum industry were read:
"Process Development in the Petroleum Industry," by J. T. Ahlin.
"The Application of a Computer to Refinery Problems," by B. D. Dagnall & P. Mayers.
"Computing Facilities in Great Britain," by J. H. Wilkinson.
"Fundamental Research in the Petroleum Industry," by M. P. Barnett.
The papers are summarized in this article.

427. *Geophysical Activity in 1955.*
H. G. Patrick, Geophysics, Vol. 22, No. 1, pp. 89-103, Jan. 1957.
Geophysical exploration throughout the world during 1955 showed an increase over 1954. An average of 1, 119 crews of all types were active during the year. This represents an increase of 83 over 1954. Statistics are given for the different methods and areas. Many tables and graphs are included.

428. *Geophysical Activity in 1956 Interim Report to Midyear.*
H. G. Patrick, Geophysics, Vol. 22, No. 1, pp. 104-119, Jan. 1957.
Geophysical exploration throughout the world during the first six months of 1956 showed a decrease of 2% from the same period of the previous year. An average of 1098 crews of all types were active. Statistics are given for the different methods and areas, illustrated by tables, charts and graphs.

429. *New Way to Evaluate Drilling Prospects.*
D. A. Mabra, Jnr., Oil & Gas J., Vol. 55, No. 5, pp. 186-188, 4th Feb. 1957.
A method is suggested by which to reduce to simple mathematical terms the underground geology and geophysics of any given area and of any given borehole, in order to evaluate and compare geological tests. Points are awarded in any given test under

three categories, as follows: Structure (four grades according to degree of control in test, etc.); Stratigraphy (varied according to no. of possible pay zones); and Proximity to Production. The result is in terms of a percentage, the maximum attainable being a 94% prospect.

430. *Search for Big Oil Pushed.*
World Petroleum, Vol. 28, No. 3, pp. 49-51, 96, 98, 100, 102, 104 & 106, March 1957.

Stimulated by the Suez crisis and the destruction of Iraq's pipelines, the oil industry has intensified its search for deposits in other parts of the world. A brief review is given of exploratory activity in 54 countries in the Americas, Europe, the Middle East, Asia and Africa.

431. *New Tools for the Geophysicist.*
World Petroleum, Vol. 28, No. 3, p. 67, March 1957.

Among the new geophysical aids discussed briefly are: electronic computing, magnetic recording, the optical analogue gravity computer, new photographic techniques, non-photographic seismic records, cables with built-in detectors, the marine sonoprobe, weight-dropping techniques, and the multiplier phototube.

432. *Purpose of Accident Reports and Statistics.*
H. Richard, Geophys. Prosp., Vol. 5, No. 1, pp. 1-8, March 1957.

The president of the E.A.E.G. Safety Committee has stated that European geophysicists fail to attach sufficient importance to accident statistics. Nevertheless these statistics are the best means at our disposal for the study of the factors influencing the number and severity of accidents.

It appears essential that two points should be stressed, firstly that the accident reports must be completed accurately, and secondly that the interpretation of each report and of the statistical data must be done systematically.

If these conditions are fulfilled it should be possible to create, at all levels, a technical and psychological atmosphere which would do much to protect geophysicists against accidents.

433. *Oil and Oceanography.*
T. F. Gaskell, World Petroleum, Vol. 28, No. 3, pp. 52-55, March 1957.

The science of oceanography has much in common with physics of the oil industry. Offshore prospecting methods are similar to those used to study the structure of the continental shelves and of the deep sea floor. The British refraction technique using sonobuoys may be useful in some marine geophysical work. Methods of interpretation of gravity, seismic and magnetic measurements developed by oceanographers may be applicable in oil exploration, and a better understanding of echo sounding is allied to seismic reflection studies. The wave and current investigations are required for designing of offshore structures, and marine biological observation and core sampling of the sea bed are closely related to studies on the formation of oil. The oceanographer and the oil man have much in common also in being both interested in observations of physical phenomena several miles below them and the instrumental techniques developed for one will apply to the other.

SEISMIC — GENERAL

434. *Firth of Forth Seismic Refraction Survey.*
W. S. Drysdale, Colliery Guardian, Vol. 191, No. 4935, pp. 379-384, 1955.

Results of a seismic refraction survey, in 1954, to determine the depth to bedrock beneath the Firth of Forth. Measurements were taken on land and under water.

435. *Exploring for Ancient Channels with the Refraction Seismograph.*
L. C. Pakiser & R. A. Black, Geophysics, Vol. 22, No. 1, pp. 32-47, Jan. 1957.

The comparatively low seismic velocity of ancient channel deposits in the Monument Valley of Arizona and Utah allow the channels to be found by the seismic refraction method. A delay-time method is used to determine depth. The problem of velocity variations is largely overcome by careful interpretation supported by drill-hole and velocity control.

436. *Index of Wells Shot for Velocity.*
V. U. Gaither, Geophysics, Vol. 22, No. 1, pp. 120-135, Jan. 1957.

This is the fifth supplement to the original Index published in the October, 1944 issue of Geophysics; other supplements appearing: October 1946, January 1949, January 1951 and January 1956. A combination of the first four lists was published in booklet form in 1953.

In this list information is given on 759 velocity surveys, most of which were shot during 1955 and 1956, in the U.S.A., Canada and Venezuela.

437. *Particle-Size Effects in Explosives at Finite and Infinite Diameters.*
M. E. Malin, A. W. Campbell & C. W. Mautz, J. Applied Phys., Vol. 18, No. 1, pp. 63-69, Jan. 1957.

The effect of particle-size variations on the detonation velocity of the two-component solid explosive, Composition B, has been studied at various diameters and shown to be important. An attempt has been made to apply the diameter-effect theory of Eyring and that of Jones to explain the experimental data, but without complete success.

Certain particle-size effects in Composition B have been shown to persist to infinite diameter, and a plausibility argument in terms of the Kirkwood-Wood theory has been offered.

The presence of large crystals in low-density RDX has been shown to lead to a "super velocity" which still prevails at infinite diameter. Experiments using large spheres of Composition B have been performed which also demonstrate a "super velocity" which may be related to the effect found in RDX.

SEISMIC — INSTRUMENTAL

438. *A New-Designed Prospecting Apparatus.*
G. Nishimura, M. Suzuki, E. Furukawa, T. Kotuki and K. Takakashi, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 30, Pt. 4, pp. 317-334, 1953.

A description, with circuit diagrams, of a seismic prospecting apparatus in which time intervals between impulses at different seismometers are measured electronically.

(From Geophys. Abstracts 163, U.S. Geol. Survey).

439. *Earthquake Seismographs and Associated Instruments.*
H. Benioff, Advances in Geophysics, Vol. 2, pp. 219-275, 1955.

A review of advancements during the past 25 years in seismographic instrumentation. A bibliography is appended.

440. *An Electronic Strong-Motion Seismograph.*
J. B. C. Taylor & L. W. Harrison, Bull. Seis. Soc. Am., Vol. 45, No. 3, pp. 179-186, 1955.

The strong-motion seismograph "type EB," designed at the New Zealand Dominion Physical Laboratory, is described. The instrument records horizontal accelerations in two directions at right angles. A 4-trace pen recorder is employed. Sensitivity curves are presented for the range 2.0-10 c.p.s.

441. *Seismic-Magnetic Data Processing.*
R. C. Dunlap, Oil & Gas J., Vol. 54, No. 76, pp. 127-132, 1956.

A description of magnetic-playback seismic recording equipment.

442. *Magnetic Tape Recording Gains Popularity; Special Report.*
World Oil, Vol. 143, No. 7, pp. 111 et seq., Dec. 1956.

A short "special report" on magnetic tape recording of seismic signals consists of three brief articles:

p. 111. "Field Application," by A. D. Waldie.
p. 112. "Frequency Responce," by T. O. Moore.
p. 113. "Seismic Data Processing," by H. T. Jones.

443. *New Techniques in Marine Geophysics.*
T. R. Goedicke & E. R. Locke, World Oil, Vol. 143, No. 7, pp. 122, 126, 128, Dec. 1956.

The authors list and briefly comment on the following developments that have increased the efficiency and accuracy of results in marine seismic surveys:

Floating Seismic Cables; Detectors (Magnetostrictive Detectors, Pressure Sensitive Detectors using a Diaphragm, Crystal Hydrophones, Velocity Geophones); Recording Methods (Magnetic Tape & Magne-Disc Recorders); Cameras (Reynolds Camera, Variable Density & Variable Area Cameras); Data Processing Methods, based on the different types of recording methods and cameras in use.

444. *Survey of Mechanical Filters and their Applications.*
J. C. Hathaway & D. F. Babcock, Proc. I.R.E., Vol. 45, No. 1, pp. 5-16, Jan. 1957.

The mechanical filter allows compact design which is consistent with the miniaturization of modern equipment.

Although numerous mechanical filter structures have been built, three types have found the most application. These are the ladder type with resonant plates interconnected by fine wires, the cylindrical rod structure machined to produce alternate necks and slugs, and a cylindrical arrangement with disc resonators interconnected by coupling wires.

Transducers used with mechanical filters provide for the converting of electrical to mechanical energy or mechanical to electrical energy and impedance matching of the filter. Of the four kinds of transducers that have been employed — electromagnetic, electrostatic, magnetostrictive, and piezo-electric — the magnetostrictive have been the most promising in regard to high frequency of operation, stability, efficiency and economy.

445 *Theory of the Electromagnetic Seismograph.*
J. P. Eaton, Bull. Seis. Soc. Am., Vol. 47, No. 1, pp. 37-75, Jan. 1957.

An attempt, guided by the work of previous investigators, has been made to clarify further the behaviour of electromagnetic seismographs by extending the theoretical treatment. Three new types of seismographs, each of which includes the classical Galitzin as a limiting case, are proposed. Methods for adjusting and calibrating these instruments are outlined.

Since overcritical damping is employed in two of the adjustments proposed, a method is given for determining the damping constant of an overdamped galvanometer or seismometer.

446. *New Offshore Exploration Tool.*
Oil Forum, Vol. 11, No. 2, pp. 61, Feb. 1957.

A tool for exploring the ocean floor, and sediments 80 feet or more beneath it, has been developed by Socony Mobil Oil Co., Inc. It is called the Marine Sonoprobe and provides reliable maps of shallow salt domes, shallow faults, buried ancient channels and valleys, and shallow geologic structures.

The sonoprobe is an echo-sounding device using sound pulses of much lower frequency and greater power than in conventional instruments.

447. *Accelerometers — Which Type for the Job?*
A. Orlacchio & G. Hieber, Elec. Ind. & Tele-Tech., Vol. 16, No. 3, pp. 75-77 & 158-160, March 1957.

Differences among the various types of accelerometers fall into four basic categories: acceleration range, frequency response, accuracy, and temperature environment. These differences are compared and are shown in tabular form.

448. *A Survey of Factors Limiting the Performance of Magnetic Recording Systems.*
E. D. Daniel, P. E. Axon & W. F. Frost, Proc. I.E.E., Vol. 104 B, No. 14, pp. 158-168, March 1957.

Various elements of a magnetic recording system, such as the heads, the tape and the tape transport mechanism, cause departures from the 'ideal' performance of the system, due either to the physical properties of the materials of which they are composed or to the limitations of the accuracy to which they can be made. Some of the effects depend fundamentally only on signal frequency and others only on recorded wavelength. This paper examines the nature and magnitude of the various departures and discusses the improved properties required in the various elements if the ideal performance is to be closely approached.

449. *Marine Sonoprobe: A New Seismic System for the Study of Recent Sediments.*
World Petroleum, Vol. 28, No. 3, pp. 60-62, March 1957.

The marine sonoprobe, developed by Magnolia Petroleum Co., is described. The device provides, very economically, valuable information about the sediments beneath a body of water. Basically, it functions like a small reflecting seismograph. Sample records taken off the U.S. Gulf Coast are discussed.

450. *Weight Dropping: A Practical Seismic Tool on Land or Water.*
A. Waldie, World Petroleum, Vol. 28, No. 3, pp. 56-59 & 80, March 1957.

Weight dropping techniques, when used in conjunction with special F. M. magnetic tape recording in the field and precision processing in the laboratory, will often solve the problem of 'bad records' from areas where reflections are poor.

Recent developments in the method are described, with illustrations, including its use on water.

451. *New Tools for the Geophysicist.*
World Petroleum, Vol. 28, No. 3, pp. 86, 88, 90, 92, & 94, March 1957.

The following developments in geophysical instruments are briefly described:

(1) All purpose seismograph camera, by Houston Technical Labs.
(2) Density Logger, by California Research Corp.
(3) Magnetic-coated discs, by Audio Devices Inc.
(4) Gravity anomaly simulator, by Houston Tech. Labs.
(5) Seismic time-domain filter system, by Houston Tech. Labs.
(6) Remote-control gravity meter, by North American Geophys. Co.
(7) Optical analogue gravity computer, by S.S.C.
(8) Vertical-force magnetometer, by Geophys. Instr. & Supply Co.
(9) Recording oscillograph, by Seismic Instruments Ltd.
(10) Electronic counter, by Hewlett-Packard Co.
(11) Recording and playback system, by Brush Electronics Co.
(12) Continuous velocity log-scale converter, by S.S.C.
(13) Central-office system, by Texas Instruments Inc.

(14) Flying laboratory, by Newmont Exploration Co.
(15) Tape recorder, by Ampex Corp.
(16) Multiplier phototube, by Allen B. Du Mont Labs.

452. *Modern Technique in Seismic Reflection Recording.*
N. A. Anstey, Geophys. Prosp., Vol. 5, No. 1, pp. 44-68, March 1957.

This paper is presented to the geophysicist concerned with the taking of seismic records in the field. Part I summarizes present knowledge of the fundamental seismic process. Part II details the manner in which this knowledge dictates the selection of some of the parameters available to the operator for controlling the quality of the records. The manner in which the recording problem is changed by the advent of magnetic recording and of automatic record computation is also discussed.

453. *Central Office Processing of Seismic Data.*
H. J. Jones, World Petroleum, Vol. 28, No. 3, pp. 68-70 & 80, March 1957.

Centralisation of seismic data processing affords many advantages in economy and efficiency. Data from many field crews can be processed fully, thus justifying the high initial cost of equipment. Magnetic records are sent from the field party to the central office which has the following equipment:

(1) magnetic playback apparatus, including a record transport and the necessary associated electronics;
(2) means of carrying out routine time corrections and computations on magnetically recorded seismic data; and
(3) means for preparing time-corrected depth records and for sections. Processed records and sections are then sent to skilled interpretation groups.

The equipment is described and the function of auxiliary apparatus discussed.

454. *How to Make Seismic Data Understood.*
K. E. Burg, Oil & Gas J., Vol. 55, No. 13, pp. 126, 139 & 141, 1st April 1957.

Advances in seismic data processing are outlined. Use of magnetic tape has made big improvements possible. The corrected record section, a product of play-back technique, is described, and some typical sections are shown.

455. *The Characteristics of Magnetic Recording Heads and Tapes.*
H. P. Spring, J. Brit. I.R.E., Vol. 17, No. 4, pp. 217-233, April 1957.

The paper deals with the functions, operating conditions and characteristics of magnetic heads and tapes. It is shown how a recording by magnetic means is made, retained on the tape and finally reproduced. The erasing of a magnetic tape by means of a steady or an alternating magnetic field is explained. The recording process is considered together with the effects caused by a.-c. biasing. Formulae for obtaining the output voltage from any given head are discussed. Demagnetization, gap functions and the various losses encountered in tape reproduction are also dealt with. Tape characteristics are discussed together with comparison graphs for different tape characteristics. Some recording heads, which differ from conventional designs, are described and their applications for various types of magnetic recordings considered. Finally, the effect of head and tape wear on the frequency response of a recorded tape are discussed quantitatively.

456. *The Analysis of Finite-Length Records of Fluctuating Signals.*
M. J. Tucker, Brit. J. Appl. Phys., Vol. 8, No. 4, pp. 137-142, April 1957.

The problem discussed is that of estimating the characteristics of a signal from a record of finite length by Fourier-type analysis or by direct measurement. The paper is an attempt to present the fundamentals of the problem in a coherent form and with the simplest possible mathematics; the results given are not new. The main discussion is of the accuracy of estimates of the power spectra and r.m.s. amplitudes of stationary random Gaussian processes: these have the characteristics of filtered random noise and include a class of signals of great practical importance. The arguments also apply to the problem of estimating the maximum speed with which a signal can be measured and analysed directly.

457. *S.S.C. Seismic Replay Center.*
World Petroleum, Vol. 28, No. 3, p. 71, March 1957.

The SSC Seismic replay center is described briefly. It consists of:
(1) a replay console;
(2) a visual display unit; and
(3) a cross-section camera.

Magnetic-field recording tapes processed by this center are corrected for weathering, elevation, and normal stepout. The corrected signals may then be composited and filtered so as to achieve the most favourable signal-to-noise ratio.

458. *S.I.E. Record Analysis System.*
World Petroleum, Vol. 28, No. 3, pp. 72, 73 & 78, March 1957.

The S.I.E. integrated seismic record-analysis system, complete in three machines, is described. Each unit is designed to perform certain functions, so that a user may purchase only the required equipment rather than invest in a more elaborate record-analysis system than is necessary. Cost of the three machines is no more than a single highly complex system to provide all the functions necessary in analysis of seismic records; and the complete units, when integrated, will produce any desired combination of functions.

459. *Carter Oil Laboratories Develop Field and Office Magnetic Machines.*
World Petroleum, Vol. 28, No. 3, pp. 74 & 75, March 1957.

The FR-1/MT-4 Field Recorder and Office Playback Machine, developed by the Carter Oil Co. is described. It provides a comprehensive and self-sufficient means for amplifying and recording 24 traces of seismic signals in a reproducible fashion with only as much amplitude control as is necessary to stay within the dynamic range of the recording medium.

460. *Geopac: an Automatic Plotter and Computer for Seismic Geophysical Data.*
L. M. Mott-Smith, W. J. Grundlach, and G. C. Phillips, World Petroleum, Vol. 28, No. 3, pp. 76-78, March 1957.

The Geopac, developed by the General Geophysical Co. for processing seismic data, is described, and its operation is discussed. The following advantages are claimed: (1) improved speed; (2) reduced human error; (3) reduced unit cost; and (4) the ability to handle and correlate large quantities of seismic data, and to present the results in the simple, organized form of a cross-section.

461. *The Gulf Seismic Profiling System.*
World Petroleum, Vol. 28, No. 3, pp. 84 & 85, March 1957.

The seismic profiling system developed by Gulf Research & Development Co. is described and its operation discussed. It displays graphically, on a photographically-printed profile, the complete seismic data recorded along a continuous traverse. The resulting profile section resembles a geologic cross-section for the seismic events are distinctively displayed by the variable density method of reproduction. Examples are shown.

SEISMIC — FIELD TECHNIQUE

462. *Modern Technique in Seismic Reflection Recording.*
N. A. Anstey, Geophys. Prosp., Vol. 5, No. 1, pp. 44-68, March 1957.

This paper is presented to the geophysicist concerned with the taking of seismic records in the field. Part I summarizes present knowledge of the fundamental seismic process. Part II details the manner in which this knowledge dictates the selection of some of the parameters available to the operator for controlling the quality of the records. The manner in which the recording problem is changed by the advent of magnetic recording and of automatic record computation is also discussed.

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Recent developments in the method are described, with illustrations, including its use on water.

SEISMIC — INTERPRETATION

464. *Effective Velocities in the Case of Continuous Variation with Depth of the True Velocities of Seismic Waves.* (In Russian).
I. S. Berzon, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 4, pp. 299-302, 1955.

A formula for the effective seismic velocity of a wave reflected from a horizontal layer, when the actual seismic velocity varies continuously with the depth, is given.

465. *Refracted Waves in Media Characterized by Small Velocity Differences.* (In Russian).
A. M. Yepinat'yeva, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 4, pp. 303-322, 1955.

If the different subsurface formations of a region have only slightly different seismic velocities, then the travel-time curves are almost parallel, and the times of arrival of refracted and reflected waves are almost the same, so that the separation of waves by their kinematic properties becomes impossible. An analytical study of the dynamic characteristics of such waves, using the acoustic method developed by L. M. Brekhovskikh leads to formulae and graphs for the changes in amplitudes taking place on the refracting boundary, and a determination of the length of the interference of both waves over the seismic profile, as well as the influence of differences in the damping capacity of the formation on the shape of the waves. The screening effect of such a boundary which can be considerable under unfavourable conditions is also discussed. The analytical results are in satisfactory agreement with the experimental data previously obtained by Yepinat'yeva.
(From Geophysical Abstracts 163, U.S. Geol. Survey).

466. *Velocity Observations by the Method of Images.* (In German).
H. J. Kortmann, Geofis. Pura e Appl., Vol. 35, No. 3, pp. 33-39, 1956.

The reflection segments determined by computations based on the method of images, as is well known, are lying too high for greater dips (not taking into account refraction effects). For the case of the top layers being horizontal, the true dip of a deeper reflection segment is determined and subsequently a graphical method given enabling quick location of the true position. For the case that, from a certain depth downward, the velocity will be constant, the angular correction can be read from a nomogram. Finally, the question is discussed when corrections will be allowed to be neglected.

467. *The Evaluation of Seismic Refraction Measurements in a Uniaxial Inhomogeneous Medium with a Restricted Exponential Series.* (In German).
M. Weber, Geofis. Pura e Appl., Vol. 35, No. 3, pp. 14-24, 1956.

The interpretation of seismic travel-time surfaces 4(r) for refracted rays is given under the assumption that 4(r) is a power series with a finite number of terms. With the results, two typical examples are treated. Finally the Herglotz solution is given in a new form.

468. *Seismic-Survey Maps Help in Development.*
N. S. Morrisey, Oil & Gas J., Vol. 55, No. 9, pp. 158-159, 4th March 1957.
The author shows how geological data from wells may be co-ordinated with recent seismic survey data to give a better picture of underground structures. The principle is here applied to the South Lucien field, Logan County, Oklahoma.

469. *Interpretation Method for Well Velocity Surveys.*
D. Walling & C. H. Savit, Geophys. Prosp., Vol. 5, No. 1, pp. 69-79, March 1957.
"Cable" and other extraneous energy in well velocity surveys may be identified and distinguished from "formation" energy by using phase relationships. Conventional instruments with at least two different narrow band-pass filters provide sufficient data to achieve good results even in the presence of extreme amounts of interference. The method is illustrated by laboratory tests and an actual well survey.

470. *The Use of a Least Squares Method for the Interpretation of Data from Seismic Surveys.*
A. E. Scheidegger & P. L. Willmore, Geophysics, Vol. 22, No. 1, pp. 9-22, Jan. 1957.
During large scale seismic surveys it is often impossible to arrange shot points and seismometers in a simple pattern, so that the data cannot be treated as simply as those of small-scale prospecting arrays. It is shown that the problem of reducing seismic observations from 'm' shot points and 'n' seismometers (where there is no simple pattern of arranging these) is equivalent to solving $(m + n)$ normal equations with $(m + n)$ unknowns. These normal equations are linear, the matrix of their coefficients is symmetric. The problem of inverting that matrix is solved here by the calculus of "Cracovians," mathematical entities similar to matrices. When all the shots have been observed at all the seismometers, the solution can even be given generally. Otherwise, a certain amount of computation is necessary. An example is given.

471. *S.S.C. Seismic Replay Center.*
World Petroleum, Vol. 28, No. 3, pp. 71, March 1957.
The SSC Seismic replay center is described briefly. It consists of:
(1) a replay console;
(2) a visual display unit; and
(3) a cross-section camera.
Magnetic-field recording tapes processed by this center are corrected for weathering, elevation, and normal stepout. The corrected signals may then be composited and filtered so as to achieve the most favourable signal-to-noise ratio.

472. *S.I.E. Record Analysis System.*
World Petroleum, Vol. 28, No. 3, pp. 72, 73 & 78, March 1957.
The S.I.E. integrated seismic record-analysis system, complete in three machines, is described. Each unit is designed to perform certain functions, so that a user may purchase only the required equipment rather than invest in a more elaborate record-analysis system than is necessary. Cost of the three machines is no more than a single highly complex system to provide all the functions necessary in analysis of seismic records; and the complete units, when integrated, will produce any desired combination of functions.

473. *Carter Oil Laboratories Develop Field and Office Magnetic Machines.*
World Petroleum, Vol. 28, No. 3, pp. 74 & 75, March 1957.
The FR.-1/MT-4 Field Recorder and Office Playback Machine, developed by the Carter Oil Co. is described. It provides a comprehensive and self-sufficient means for amplifying and recording 24 traces of seismic signals in a reproducible fashion

with only as much amplitude control as is necessary to stay within the dynamic range of the recording medium.

474. *Geopac: An Automatic Plotter and Computer for Seismic Geophysical Data.*
L. M. Mott-Smith, W. J. Grundlach, and G. C. Phillips, World Petroleum, Vol. 28, No. 3, pp. 76-78, March 1957.

The Geopac, developed by the General Geophysical Co. for processing seismic data, is described, and its operation is discussed. The following advantages are claimed: (1) improved speed; (2) reduced human error; (3) reduced unit cost; and (4) the ability to handle and correlate large quantities of seismic data, and to present the results in the simple, organized form of a cross-section.

475. *The Gulf Seismic Profiling System.*
World Petroleum, Vol. 28, No. 3, pp. 84 & 85, March 1957.

The seismic profiling system developed by Gulf Research & Development Co. is described and its operation discussed. It displays graphically, on a photographically-printed profile, the complete seismic data recorded along a continuous traverse. The resulting profile section resembles a geologic cross-section, for the seismic events are distinctively displayed by the variable density method of reproduction. Examples are shown.

476. *Exploring for Ancient Channels with the Refraction Seismograph.*
L. C. Pakiser & R. A. Black, Geophysics, Vol. 22, No. 1, pp. 32-47, Jan. 1957.

The comparatively low seismic velocity of ancient channel deposits in the Monument Valley of Arizona and Utah allow the channels to be found by the seismic refraction method. A delay-time method is used to determine depth. The problem of velocity variations is largely overcome by careful interpretation supported by drill-hole and velocity control.

477. *Seismic-Magnetic Data Processing.*
R. C. Dunlap, Jr., Oil & Gas J., Vol. 54, No. 76, pp. 127-132, 1956.

A description of magnetic-playback seismic recording equipment.

478. *Magnetic Tape Recording Gains Popularity: Special Report.*
World Oil, Vol. 143, No. 7, pp. 111 et seq, Dec. 1956.

A short "special report" on magnetic tape recording of seismic signals consists of three brief articles:

p. 111. "Field Application," by A.D. Waldie.
p. 112. "Frequency Response," by T. O. Moore.
p. 113. "Seismic Data Processing," by H. T. Jones.

479. *New Techniques in Marine Geophysics.*
T. R. Goedicke & E. R. Locke, World Oil, Vol. 143, No. 7, pp. 122, 126 & 128, Dec. 1956.

The authors list and briefly comment on the following developments that have increased the efficiency and accuracy of results in marine seismic surveys:

Floating Seismic Cables; Detectors (Magnetostrictive Detectors, Pressure Sensitive Detectors using a Diaphragm, Crystal Hydrophones, Velocity Geophones); Recording Methods (Magnetic Tape & Magne-Disc Recorders); Cameras (Reynolds Camera, Variable Density & Variable Area Cameras); Data Processing Methods, based on the different types of recording methods & cameras in use.

480. *Central Office Processing of Seismic Data.*
H. J. Jones, World Petroleum, Vol. 28, No. 3, pp. 68-70 & 80, March 1957.

Centralisation of seismic data processing affords many advantages in economy and efficiency. Data from many field crews can be processed fully, thus justifying the high initial cost of equipment. Magnetic records are sent from the field party to the central office which has the following equipment:

(1) magnetic playback apparatus, including a record transport and the necessary associated electronics;

(2) means of carrying out routine time corrections and computations on magnetically recorded seismic data; and

(3) means for preparing time-corrected depth records and for sections. Processed records and sections are then sent to skilled interpretation groups.

The equipment is described and the function of auxiliary apparatus discussed.

481. *Modern Technique in Seismic Reflection Recording.*
N. A. Anstey, Geophys. Prosp., Vol. 5, No. 1, pp. 44-68, March 1957.

This paper is presented to the geophysicist concerned with the taking of seismic records in the field. Part I summarizes present knowledge of the fundamental seismic process. Part II details the manner in which this knowledge dictates the selection of some of the parameters available to the operator for controlling the quality of the records. The manner in which the recording problem is changed by the advent of magnetic recording and of automatic record computation is also discussed.

482. *How to Make Seismic Data Understood.*
K. E. Burg, Oil & Gas J., Vol. 55, No. 13, pp. 136, 139 & 141, 1st April 1957.

Advances in seismic data processing are outlined. Use of magnetic tape has made big improvements possible. The corrected record section, a product of play-back technique, is described, and some typical sections are shown.

483. *The Analysis of Finite-Length Records of Fluctuating Signals.*
M. J. Tucker, Brit. J. Appl. Phys., Vol. 8. No. 4, pp. 137-142, April 1957.

The problem discussed is that of estimating the characteristics of a signal from a record of finite length by Fourier-type analysis or by direct measurement. The paper is an attempt to present the fundamentals of the problem in a coherent form and with the simplest possible mathematics: the results given are not new. The main discussion is of the accuracy of estimates of the power spectra and r.m.s. amplitudes of stationary random Gaussian processes: these have the characteristics of filtered random noise and include a class of signals of great practical importance. The arguments also apply to the problem of estimating the maximum speed with which a signal can be measured and analysed directly.

SEISMIC — THEORY & RESEARCH

484. *Transmission and Reflection of Seismic Waves through Multilayered Elastic Media.*
T. Matumoto, Tokyo Univ. Earthquake Res. Inst. Bull., Vol, 31, Pt. 4, pp. 261-273, 1953.

Expressions are obtained for the amplitude of transmitted and reflected wave for incident dilatational and distortional waves using matrix methods. Numerical examples are included.

(From Geophysical Abstracts 163, U. S. Geol. Survey).

485. *Study on Surface Waves XII. Non-Dispersive Surface Waves.*
Y. Sato, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 32, Pt. 4, pp. 349-360, 1954.

A study of the only three possible non-dispersive surface waves: Rayleigh waves, Stoneley waves and [EE/E]waves.

486. *An Experimental Study on Seismic Waves.*
T. Kaneko & K. Tazime, Butsuri-Tanko, Vol. 7, No. 4, pp. 179-185, 1954.

Four waves were observed in experimental observations within 30 m. Two are believed to be surface waves. Motion in these at several distances has been sketched from the seismograms.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

487. *Frequency Analysis of Seismic Vibrations.* (In Russian).
G. V. Bereza, A. I. Slutskovskiy & M. K. Polshkov, Prikladnaya Geofiz., Vol. 11, pp. 92-123, 1954.

The procedure for frequency analysis of seismic waves, using 24 sharply tuned galvanometers and a broadly tuned amplifier, is described in detail. Several of the resulting records are shown.

488. *High-Frequency Seismic Surveying.* (In Russian).
G. A. Gamburtsev & I. S. Berzon, Akad. Nauk SSSR, Dokl., Vol. 101, No. 5, pp. 841-844, 1955.

Use of high-frequency seismic waves makes it possible to obtain refracted waves from depths 1-500 m. and reflected waves from depths as great as 2,000 m. The resulting seismograms are free of microseismic or industrial disturbances, and of wind disturbances. Resolving powers are increased, allowing determination of structures only 5 m. thick. Propagation of h.-f. seismic waves uses more explosive which has to be buried deeper in denser rock. Waves of 70-400 c.p.s. (compared with the normal 25-70 c.p.s.) are produced. Instruments have to be of higher sensitivity.

489. *On the Visco-Elastic Waves Radiated from a Spherical Cavity in Elastico-Viscous Medium.*
K. Iida & H. Aoki, Nagoya Univ. J. Earth Sci., Vol. 3, No. 2, pp. 105-126, 1955.

The displacement in the wave that results from application of a pressure pulse to the interior of a spherical cavity in an elastico-viscous medium is a damped sinusoidal displacement with amplitude proportional to pressure, area of the cavity, and dimensionless relaxation, and inversely proportional to the rigidity. The velocity of the wave front is in close agreement with that in a perfectly elastic medium. Attenuation of the wave increases with distance from the source. Non-oscillatory deformation is produced in the vicinity of the spherical cavity. The wave motion is more closely related to that in a perfectly elastic medium than in a firmo-viscous medium.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

490. *Amplitudes and Travel-Time Curves of Waves Produced in Homogeneous Perfectly Elastic Medium by a Harmonic Concentrated Force.* (In Russian).
I. P. Kosminskaya, Akad. Nauk SSSR Geofiz. Inst. Trudy, No. 30, (157), pp. 286-301, 1955.

The amplitude and travel-time curves of waves produced in an ideally elastic homogeneous medium by a concentrated harmonically varying force, applied at a point of the medium, have been studied by adapting formulae to the specific conditions of the problem as suggested by Gamburtsev. Results indicate that near the source of the disturbance the motion is complicated. (The composite wave propagates here with the velocity of transverse waves), and at distances greater than twice the wavelength of the transverse wave, in the direction of the force, longitudinal waves predominate, their amplitude being five or more times greater than the amplitude of transverse waves. In the direction perpendicular to the acting force the predominant vibration is the transverse wave.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

491. *Effective Velocities in the Case of Continuous Variation with Depth of the True Velocities of Seismic Waves.* (in Russian).
I. S. Berzon, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 4, pp. 299-302, 1955.
A formula for the effective seismic velocity of a wave reflected from a horizontal layer, when the actual seismic velocity varies continuously with the depth is given.

492. *Refracted Waves in Media Characterized by Small Velocity Differences.* (In Russian).
A. M. Yepinat'yeva, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 4, pp. 303-322, 1955.
If the different subsurface formations of a region have only slightly different seismic velocities, then the travel-time curves are almost parallel, and the times of arrival of refracted and reflected waves are almost the same, so that the separation of waves by their kinematic properties becomes impossible. An analytical study of the dynamic characteristics of such waves, using the acoustic method developed by L. M. Brekhovskikh leads to formulae and graphs for the changes in amplitudes taking place on the refracting boundary, and a determination of the length of the interference of both waves over the seismic profile, as well as the influence of differences in the damping capacity of the formation on the shape of the waves. The screening effect of such a boundary which can be considerable under unfavourable conditions is also discussed. The analytical results are in satisfactory agreement with the experimental data previously obtained by Yepinat'yeva.
(From Geophys. Abstracts 163, U.S. Geol. Survey).

493. *Velocity Observations by the Method of Images.* (In German).
H. J. Kortmann, Geofis. Pura e Appl., Vol. 35, No. 3, pp. 33-39, 1956.
The reflection segments determined by computations based on the method of images, as is well known, are lying too high for greater dips (not taking into account refraction effects). For the case of the top layers being horizontal, the true dip of a deeper reflection segment is determined and subsequently a graphical method given enabling quick location of the true position. For the case that, from a certain depth downward, the velocity will be constant, the angular correction can be read from a nomogram. Finally, the question is discussed when corrections will be allowed to be neglected.

494. *On Forms of Seismic Waves Generated by Explosion II.*
Z. Suzuki & H. Sima, Tohoku Univ. Sci. Repts., 5th Ser., Vol. 6, No. 3, pp. 162-170, 1955.
Wave motion from the detonation of a cap consists of several regular wave groups, which are governed by a simple law of propagation, and an irregular part that is apparently the result of the superposition of regular waves. Waveform varies widely even within the distance range of one or two wavelengths, which is not in agreement with mathematical studies on elastic or visco-elastic waves unless an unreasonably large viscosity is assumed.
(From Geophysical Abstracts 165, U.S. Geol. Survey).

495. *The Seismic Surface Pulse.*
C. L. Pekeris, Nat. Acad. Sci. Proc., Vol. 41, No. 7, pp. 469-480, 1955.
Exact and closed expressions are derived for both the horizontal displacement $q(t)$ and the vertical displacement $w(t)$ of the surface of a uniform elastic half-space due to the application at the surface of a point pressure pulse varying with time like the Heaviside unit function $H(t)$. Both are of the form $(1/r)f(T)$ where $T = (ct/r)$ and c is the shear velocity. Both horizontal and vertical displacements become infinite at the time of arrival of the Rayleigh wave, but the arrival of the shear wave is marked only by a change in the slope of the displacements.
(From Geophys. Abstracts 165, U.S. Geol. Survey).

496. *Methods of Analysing the Curves of the Amplitudes and the Travel-Time Curves of the Phases Forming Composite Harmonic Waves.* (In Russian).
I. P. Kosminskaya, Akad. Nauk SSSR Geofiz., Inst. Trudy, No. 30, (157), pp. 302-313, 1955.

Graphical methods are described which make possible the determination of the component waves, if the composite wave is known. This problem in general has an infinite number of solutions, but can be solved with good approximation when the component amplitudes as well as the phases are very different. If the component amplitudes and phases are found, the travel-time curves of individual waves can also be determined.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

497. *Analysis of Dispersed Surface Waves by Means of Fourier Transform I.*
Y. Sato, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 33, Pt. 1, pp. 33-47, 1955.

The amplitude and the phase angle of the Fourier transform of the curve observed at any station express the spectrum near the origin and the phase shift caused by the propagation. Dispersion curves so obtained are in good agreement with those determined by the conventional method measuring intervals between crests. As an example a dispersion curve is computed for the record of an explosion at Lake Haruna and thickness of the ice estimated as 31.5 cm., in good agreement with the observed thickness of 34 cm.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

498. *Range of Possible Existence of Rayleigh- and Sezawa-Waves in a Stratified Medium.*
R. Yamaguchi & Y. Sato, Tokyo Univ. Earthquake Res. Inst. Bull., Vol. 33, Pt. 3, pp. 265-273, 1955.

A precise calculation of the critical boundary between the existence and non-existence of Rayleigh- and Sezawa-waves in a stratified medium under given relations of wavelength to thickness of layer, of rigidity in the layer to that in the substratum, and of S-wave velocity in the layer to that in the substratum. Results are shown graphically.

499. *The Generation of Waves in an Infinite Elastic Solid by Variable Body Forces.*
G. Eason, J. Fulton & I. N. Sneddon, Phil. Trans. Roy. Soc., A., Vol. 248, No. 955, pp. 575-607, 1956.

This paper is concerned with the determination of the distribution of stress in an infinite elastic solid when time-dependent body forces act upon certain regions of the solid.

500. *The Propagation of Elastic Waves in a Layer Lying on an Elastic Base.* (In Russian).
P. K. Ishkov, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 124-133, 1956.

An analysis, based on Lamb's method, of the propagation of waves along the boundary of an elastic layer overlying an elastic base. The materials of both layers are considered incompressible. Tables and graphs are provided for solving the same problem for different elastic properties of the layers.

501. *Asymmetric Interference Waves in a Multilayer Medium.* (In Russian).
V. I. Keylis-Borok, Akad. Nauk SSSR Doklady, Vol. 107, No. 4, pp. 533-536, 1956.

The propagation of elastic waves through an axially symmetric multilayer medium is generalized so the only limitation imposed is that the semispace is formed of plane parallel elastic layers, and the problem solved in a general form. It is shown that waves of two kinds are produced: those with displacements in the vertical radial plane, and those with horizontal tangential displacements. Both kinds of waves can be used in investigations of the damping of surface waves in the crust of the earth.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

502. *The Change in the Predominant Frequency of Seismic Waves with Increasing Distance from the Source of Vibrations.* (In Russian).
I. S. Berson, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 1, pp. 3-22, 1956.

The frequencies of seismic waves are found to be lower with increasing distance from the source. The effect of this is considered from the viewpoint of selecting proper conditions for a seismic survey.

503. *Amplitude of Curves and Travel-Time Curves of Seismic Waves on the Free Boundary of Semispace.* (In Russian).
I. P. Kosminskaya, Akad. Nauk SSSR Izv. Ser. Geofiz., No. I, pp, 37-47, 1956.

Determination of amplitudes and velocities of waves predominantly Rayleigh type, propagated on the surface of the earth by vertical harmonic impulses from electromagnetic or piezoelectric vibrators on the surface. The ground is assumed to be ideally elastic.

504. *Certain Types of Multiple Seismic Waves.* (In Russian).
A. M. Yepinat'yeva, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 1, pp. 23-36, 1956.

A study of multiple waves caused by the wave reflected above the shot point. This becomes opposite in phase. Arrival time increases with the depth of the shot point. The multiple reflections cause interference when depth of shot is small.

505. *Disturbances in Different Types of Elastic Media.*
S. K. Chakraborty, Geofis. Pura e Appl., Vol. 35, No. 3, pp. 25-32, 1956.

Disturbances generated by pressure on the surface of a spherical cavity inside (i) a dispersive medium (ii) a medium having transverse isotropy about the radius vector have been considered. Finally, a brief discussion of the propagation of waves in visco-elastic media has been added.

506. *Electrostatic Analogy to Sound in a Region of Constant Velocity Gradient.*
L. Mittenthal, J. Acoust. Soc. Am., Vol. 29, No. 1, pp. 149-150, Jan. 1957.

Using ray theory a wave front is found for the case of sound from a point source in a medium where sound velocity is proportional to depth. The spreading backwards toward the source is shown to be independent of ray angle. The rays are shown to be harmonic functions similar to lines of flux. The harmonic conjugate to the ray is derived and shown to resemble an electrostatic potential.

507. *Stonely-Wave Velocities for a Fluid-Solid Interface.*
E. Strick & A. S. Ginzbarg, Bull. Seis. Soc. Am., Vol. 46, No. 4, pp. 281-292, Oct. 1956.

By means of an iteration technique employing an Elecom 120 digital computer, numerical solutions V_{ST}/b and $V_{ST}/c = b/c\ (V_{ST}/b)$ have been obtained with better than four significant figure accuracy for the following parameter values:

$\frac{p^f}{p^s} = 0.20,\ 0.37,\ 0.45,\ 0.56,\ 0.70,\ 0.80,\ 0.90,\ 1.00,\ 1.10,\ 1.25,\ 1.38,\ 2.00$ and 3.00.

$\sigma = 0.05,\ 0.10,\ 0.15,\ 0.20,\ 0.25,\ 0.30,\ 0.35,\ 0.40$ and 0.45.

where p, ${}^fc$ = density and dilatational velocity of fluid.

p, ${}^sa$, b, σ = density, dilatational and shear (rotational) velocities, and Poisson's ratio of solid.

V_{ST} = Stonely-wave velocity.

The graphs of the tabulated data appear in the order of increasing σ, with p^f/p^s as a parameter.

508. *Variation of Elastic Wave Velocities in Basic Igneous Rocks with Pressure and Temperature.*
D. S. Hughes & C. Maurette, Geophysics, Vol. 22, No. 1, pp. 23-31, Jan. 1957.

The dilatational and rotational wave velocities have been measured as functions of pressure and temperature for three gabbros, two basalts and a dunite. The pressure range was 200-6,000 bars. The temperature range was 25-300°C and 400°C for one sample. The maximum pressure is equivalent to 23 km. of depth and the highest temperature is believed to correspond to 25 km. The data indicate a tendency for the velocity to reach a maximum somewhere between 10 and 20 km. and then decrease slightly.

509. *Anisotropy in Rocks under Simple Compression.*
D. Tocher, Trans. A.G.U., Vol. 38, No. 1, pp. 89-94, Feb. 1957.

Compressional velocities through samples of several types of rocks have been measured while the samples were subjected to simple compression in a hydraulic press. Velocity measurements were made in directions parallel to and perpendicular to the direction of the compression, with the amount of compression varying from zero up to the rupture point. All measurements were made at room temperature and with no confining pressure other than that of the atmosphere.

510. *Wave Propagation in Elastic Plates: Low and High Mode Dispersion.*
I. Tolstoy & E. Usdin, J. Acoust. Soc. Am., Vol. 29, No. 1, pp. 37-42, Jan. 1957.

This is an analysis of dispersive properties of elastic plates in vacuo. For low modes there exists conclusive experimental verification of these properties. Model studies show prominent arrivals having the proper spectra and velocities for group velocity maxima and minima corresponding to several symmetric and anti-symmetric modes. In addition, detailed calculations based upon exact formulae predict some new and as yet unconfirmed properties of plates, e.g., negative phase velocities. New results concerning high modes of propagation are also displayed. These modes are of considerable theoretical interest since they belong to the transition region between the domains of validity of the wave and ray theories. The structure of the symmetric and anti-symmetric fiftieth mode dispersion curves illustrates that for a given angle of incidence the propagating energy will be either chiefly shear or chiefly compressional, passage from one to the other corresponding to energy transfer between symmetrical and anti-symmetrical modes of propagation. Comparison with multilayered liquid wave guides are mentioned.

511. *Formulation of Wave Propagation in Infinite Media by Normal Co-Ordinates with an Application to Diffraction.*
M. A. Biot & I. Tolstoy, J. Acoust. Soc. Am., Vol. 29, No. 3, pp. 381-391, March 1957.

In the theories of acoustical and e.m. vibrations of enclosures, as well as in field theory and electro-dynamics, one quite commonly uses normal modes as generalized co-ordinates in Hilbert space. Here the method is extended to unlimited or partially limited mechanical media, essentially by first solving the problem for an enclosure and going to a limit while expanding all or some of the boundaries to infinity.

512. *Scattering in an Inhomogeneous Medium.*
E. Skudrzyk, J. Acoust. Soc. Am., Vol. 29, No. 1, pp. 50-60, Jan. 1957.

The standard mathematical procedure formally describes scattering by the superposition of a scattered pressure on the unscattered sound field. At low frequencies, because of the irregular distribution of the inhomogeneities, the phases of the scattered waves are at random and scattering is an interference phenomenon. As the frequency increases, scattering becomes highly collimated in the forward direction and the phase differences decrease to zero. At this point ray theory starts to apply. The scattered pressure, then, essentially describes only a phase change caused by the different sound velocities and the focusing and defocusing by the lens action of the patches.

The medium in the neighbourhood of the receivers can be shown to contribute only be focusing, the medium farther away only by interference fluctuations. Focusing leads to normally distributed amplitude fluctuations. The distribution of the interference fluctuations, however, passes from normal to Rayleigh with increasing values of range.

513. *Absorption of Sound by Patches of Absorbent Materials.*
R. K. Cook, J. Acoust. Soc. Am., Vol. 29, No. 3, pp. 324-329, March 1957.

Circular patches or long strips of sound absorbent material are on the surface of an infinite perfectly reflecting plane. Exact solutions are found for the absorption of perpendicularly incident plane waves, and of randomly incident waves, on a circular piston-like absorber. An exact solution is found for the absorption of perpendicularly incident plane waves on an infinitely long strip-piston absorber. The basis of the technique is a representation of the total wave field by superposition of an incident plane wave, a specularly reflected plane wave, and a scattered wave. The last-named is in turn represented by a superposition of plane waves for the strip-piston, and by a superposition of cylindrical waves for the circular piston absorber. The superposed wave fields are adjusted to meet the boundary conditions.

514. *Reflection of Plane Sound Waves from a Sinusoidal Surface.*
J. G. Parker, J. Acoust. Soc. Am., Vol. 29, No. 3, pp. 377-380, March 1957.

The problem of calculating the specular component of the sound field reflected from a sinusoidal pressure release surface is discussed. The incident field is assumed to be plane and directed normally to the surface. Basically, the problem consists of obtaining the solution to a non-linear differential equation derived in an earlier paper. This was done numerically and the results compared with existing experimental data on sound reflection from two differently formed surfaces. In one case agreement between calculated and measured values is quite good while in the second case there is considerable discrepancy. A possible explanation of this discrepancy is given.

515. *The Transmission of Rayleigh Waves across an Ocean Floor with Two Surface Layers. Part I. Theoretical.*
R. Stoneley, Bull. Seis. Soc. Am., Vol. 47, No. 1, pp. 7-12, Jan. 1957.

The theoretical part of this paper is a discussion of the propagation of waves of Rayleigh type in an elastic medium with a horizontal double surface layer, above which is a uniform layer of liquid. This model is based on seismic determinations of the velocities of explosion waves in the layers below the ocean bottom, and the equation giving the wave velocity as a function of wave length is derived as a determinantal equation of the eleventh order.

The numerical solution of this equation and the application to the propagation of Rayleigh waves across the ocean floor will be given in Part II.

GRAVITY — GENERAL

516. *Gravity Anomalies at Continental Margins.*
J. L. Worzel & G. L. Shurbet, Proc. Nat. Acad. Sci., Vol. 41, No. 7, pp. 458-469, 1955.

517. *Regional Gravity in the Eastern and Central Commonwealth of Australia.*
C. E. Marshall & H. Narain, Sydney Univ., Dept. of Geology & Geophys. Mem. 1954/2, 101 p., 1954.

518. *Interpretations of Gravimetric and Magnetic Anomalies on Traverses in the Canadian Shield in Northern Ontario.*
G. D. Garland, Dominion Observ. Ottawa Pubs., Vol. 16, No. 1, pp. 1-57, 1950.

519. *Gravity Prospecting in Southwestern Ontario.*
W. B. Dyer, Canadian Oil & Gas Industries, Vol. 9, No. 3, pp. 37-43, 1956.

520. *Application of Gravimeter Observations to the Determination of the Mean Density of the Earth and of Rock Densities in Mines.*
A. H. Miller & M. J. S. Innes, Dominion Observatory Ottawa Pubs., Vol. 16, No. 4, pp. 3-17, 1953.
A density profile obtained from gravity measurements at Noranda, Ontario, shows a direct relation between density and the occurrence of ore. This suggests that gravity measurements may be used to indicate the likelihood of ores.

521. *The Geological Results of Measurements of Gravity in the Welsh Borders.*
A. H. Cook & H. I. S. Thirlaway, Geol. Soc. London, Q. J., Vol. III, Pt. 1, pp. 47-70, 1955.
The results of gravity measurements in the Welsh Borders are presented as a Bouguer anomaly map.

522. *Gravimetric Survey in the Adriatic Sea.* (In Italian).
C. Morelli, La Ricerca Sci., Vol. 25, No. 10, pp. 2845-2872, 1955.
The results of gravity measurements in the Adriatic Sea are presented in detailed tables and as a Bouguer anomaly map.

523. *On the Comparison of Gravimetric and Magnetic Anomalies in the Sahara.* (In French).
J. Castet & J. Lagrula, Acad. Sci. Paris Comptes Rendus, Vol. 241, No. 1, pp. 84-86, 1955.
Comparison between isostatic anomalies for depth of compensation of 20 km. and vertical magnetic anomalies shows the agreement is marked in some places, but of opposite sign with the positive gravity anomaly corresponding to a negative magnetic anomaly.
(From Geophys. Abstracts 163, U.S. Geol. Survey).

524. *Geologic Application of Gravity Surveys.* (In French).
J. Goguel, Ann. des Mines, Vol. 144^{e}, No. 5, pp. 26-37, 1955.
A review of gravity theory, including interpretation of local anomalies, corrections, and determination of residual anomalies.

525. *On some Gravimetric and Electrical Surveys in South-Central Italy.* (In Italian).
G. Zaccara, Serv. Geol. Italia Boll., Vol. 76, No. 2, pp. 617 & 618, 1955.

526. *Determination of the Regional Gravity Gradient in the Area of the Plains of the Garigliano and the Lower Volturno (Campania).* (In Italian with English, French and German summaries).
F. Falini, La Ricerca Sci., Vol. 26, No. 4, pp. 1134-1149, 1956.

527. *Structural Interpretation of the Gravity Survey of Madagascar.* (In French).
L. Cattala, Inst. Sci. Madagascar Mem., Ser. D., Vol. 6, pp. 35-41, 1954.

528. *An Interpretation of Gravity Anomalies in the Eastern Mediterranean.*
J. C. Harrison, Phil. Trans. Roy. Soc., A., Vol. 248, No. 947, pp. 283-325, 1955.

529. *Gravity Reconnaissance Survey of Puerto Rico.*
G. L. Shurbet & M. Ewing, Bull. Geol. Soc. Am., Vol. 67, No. 4, pp. 511-534, 1956.

530. *Gravity Data and Crustal Warping in Northwest Pakistan and Adjacent Parts of India.*

E. A. Glennie, Mon. Not. Roy. Astronom. Soc., Geophys. Supple., Vol. 7, No. 4, pp. 162-175, Aug. 1956.

A new gravity anomaly is introduced and used by an original method, which leads automatically to the detailed contouring of the basement rock below the region, the basement being assumed to be the upper surface of the earth's crust. The standard crustal section employed is a two-layer crust with a total thickness of 30 km. but a table permits direct comparison with other sections of a six-layer crust, two of which have increased thickness.

531. *Trial Interpretation of Certain Gravity Anomalies in the Western Mediterranean and Northern Africa.* (In French).
H. de Cizancourt, Ann. Geophys., Vol. 9, No. 2, pp. 126-154, 1953.

532. *Gravity Observations at Sea in USS Conger. Cruise III.*
G. L. Shurbet & J. L. Worzel, Trans. A.G.U., Vol. 38, No. 1, pp. 1-7, Feb. 1957.

Principal facts, including free-air and simple Bouguer anomalies, are presented for 60 gravity observations at sea. A Vening Meinesz pendulum apparatus was used during the gravity measuring cruise of USS Conger (SS 477), Cruise III.

Excluding anomalies associated with the Puerto Rico Trench and the continental margin, free-air anomalies observed on a line between San Juan, P.R., and New London, Conn., are -10 to -50 mgal. If the standard oceanic crustal section of Worzel and Shurbet is adopted as a reference, these anomalies can be explained by variations of the sediment or, the crustal rock thicknesses of not more than 1 km. from normal oceanic thicknesses, or both.

533. *Submarine Gravity Measurements in the Atlantic Ocean, Indian Ocean, Red Sea and Mediterranean Sea.*
R. W. Girdler & J. C. Harrison.

The results are given of 58 gravity measurements made at sea in H. M. Submarine 'Acheron' between April and October, 1955. Of these, 6 lie in the N. Atlantic, 8 in the S. Atlantic and 37 in the Indian Ocean. The remainder are in the Red Sea (4), the Mediterranean (2) and off the Isle of Wight (1).

GRAVITY — INSTRUMENTAL

534. *Calibration of Gravimeters by the Vertical Gradient of Gravity.* (In Spanish).
L. Lozano Calro, Rev. Geofis., Vol. 14, No. 55, pp. 209-218, 1955.

The vertical gradient of gravity is used to calibrate gravimeters. Formula and method are given.

535. *Quartz Gravimeter for the Determination of the Gravimetric Base Stations.* (In Russian).
Y. D. Bulanzke & E. I. Popov, Akad. Nauk SSSR Geofiz., Inst. Trudy, No. 30 (157), pp. 240-249, 1955.

A description of the GAE-2 gravimeter which is based on the Nørgaard gravimeter. With it, gravity measurements can be made with errors of a fraction of a milligal.

536. *A Procedure for the Calibration of Gravimeters.*
M. Caputo, Geofis. Pura e Appl., Vol. 35, No. 3, pp. 8-13, 1956.

Taking into account some recent results showing that the observations carried out with Worden gravimeters are influenced by temperature, a method of calibration has been followed which aims to neutralize both the effect of drift and to afford complete symmetry to every value observed.

537. *Improvements in Tidal Gravity Meters and their Simultaneous Comparison.*
H. N. Clarkson & L. J. B. La Coste, Trans. A.G.U., Vol. 38, No. 1, pp. 8-16, Feb. 1957.

The measurements obtained in instruments such as tidal gravity meters have led to the development of a photoelectric optical system that is not subject to the forms of drift associated with most reading systems of this type. In addition a much improved servo-system with a compensating network has been employed in these measurements and is described. The results of measurements made at Austin, Texas with two tidal gravity meters recording simultaneously are given. They indicate an accuracy of better than 1 microgal.

538. *Field Techniques and Problems in Offshore Gravity Program.*
V. M. Lynch, World Petroleum, Vol. 28, No. 3, pp. 65-66, March 1957.

The entire offshore area between Sabine Pass, Texas and New Orleans, Louisiana, is at present being studied by the gravity method. Anomalous areas will later be examined in more detail by seismic and other geophysical methods.

The gravity observations are being made using remote controlled underwater gravimeters and pressure gauges. Operating procedure is discussed briefly.

539. *Accelerometers — Which Type for the Job?*
A. Orlacchio & G. Hieber, Elec. Ind. & Tele-Tech., Vol. 16, No. 3, pp. 75-77 & 158-160, March 1957.

Differences among the various types of accelerometers fall into four basic categories: acceleration range, frequency response, accuracy and temperature environment. These differences are compared and are shown in tabular form.

GRAVITY — FIELD TECHNIQUE

540. *Field Techniques and Problems in Offshore Gravity Program.*
V. M. Lynch, World Petroleum, Vol. 28, No. 3, pp. 65 & 66, March 1957.

The entire offshore area between Sabine Pass, Texas and New Orleans, Louisiana, is at present being studied by the gravity method. Anomalous areas will later be examined in more detail by seismic and other geophysical methods.

The gravity observations are being made using remote controlled underwater gravimeters and pressure gauges. Operating procedure is discussed briefly.

GRAVITY — INTERPRETATION

541. *The Method of Analysis for Gravitational Prospecting.* (In Japanese with English summary).
A. Matsuzawa, Butsuri-Tanko, Vol. 6, Nos. 3-4, pp. 213-222, 1953.

Ambiguity in interpretation of gravity surveys is reduced by use of independent data such as drilling logs or seismic data, or by use of residual gravity and second derivative methods.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

542. *Geologic Application of Gravity Surveys.* (In French).
J. Goguel, Ann. des Mines, Vol. 144^{e}, No. 5, pp. 26-37, 1955.

A review of gravity theory, including interpretation of local anomalies, corrections and determination of residual anomalies.

543. *On a New Method of Determination of Mean Density.* (In Hungarian).
L. Egyed, Magyar Allami Eötvös Lorand Geofiz., Int., Geofiz. Közlem., Vol. 4, No. 2, pp. 31-36, 1955.

An extension of the Nettleton density determination.

544. *Instrument for Computing Poisson's Integral and some of its Applications.* (In Russian).
S. P. Kapitsa, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 4, pp. 369-376, 1955.

In both magnetic and gravimetric surveying it is often necessary to recalculate the observed data from one level to another, which involves computation of Poisson's integral, satisfying the Laplace equation controlling the related field pattern. To reduce the numerical work required, an instrument was designed and built in the Geophysical Institute of the Academy of Sciences of the U.S.S.R. The instrument is similar in appearance and handling to Amsler's planimeter, and it determines the numerical value of the integral with an error smaller than that admitted in the initial measurements. The theory of the operation of the instrument is discussed and its use illustrated on several examples.

(From Geophys. Abstracts 163, U.S. Geol. Survey).

545. *A Note on Gravitational Interpretation.*
G. M. Ball, Mines Mag., Vol. 46, No. 4, pp. 42-43, 1956.

A brief discussion on the interpretation of isogal and second derivative maps.

546. *The Interpretation of Magnetic and Gravitational Anomalies by the Method of the Exclusion of Elementary Field.* (In Russian).
D. S. Mikov, Akad. Nauk SSSR Izv. Ser. Geofiz., No 2, pp. 218-225, 1956.

For the interpretation of gravitational or magnetic anomalies of two-dimensional bodies, it is suggested that it be assumed that the disturbing body is composed of a number of prisms of the same density or magnetic properties and filling completely the volume occupied by the body. For every elementary prism it is possible under certain assumptions to evaluate its part in the anomaly. By consecutively subtracting these contributions of individual prisms or combinations of prisms until the total anomaly is exhausted, the shape of the disturbing body is found. Four alignment charts and two tables of numerical values facilitate the procedure.

(From Geophysical Abstracts 165, U.S. Geol. Survey).

547. *Correlation of Rock Density Determinations for Gravity Survey Interpretation.*
J. T. Whetton, J. O. Myers & R. Smith, Geophys. Prosp., Vol. 5, No. 1, pp. 20-43, March 1957.

The results of field and laboratory methods of density determination on a series of Coal Measure, Permian and Triassic rocks are presented and the different methods compared. It is concluded that the most satisfactory method is that of measuring the vertical change of gravity in a mine shaft. Nettleton's method is unsatisfactory to us, due to weathering effects from drift. Laboratory measurements are of variable value depending on the lithology and source of the samples.

A method adopted to solve the problem of finding the true densities for use in a local gravity survey in N.E. England is given.

GRAVITY — THEORY & RESEARCH

548. *Geologic Application of Gravity Surveys.* (In French).
J. Goguel, Ann. des Mines, Vol. 144^{e}, No. 5, pp. 26-37, 1955.

A review of gravity theory, including interpretation of local anomalies, corrections and determination of residual anomalies.

549. *Application of Gravimeter Observations to the Determination of the Mean Density of the Earth and of Rock Densities in Mines.*
A. H. Miller & M. J. S. Innes, Dominion Observatory, Ottawa Pubs., Vol. 16, No. 4, pp. 3-17, 1953.

A density profile obtained from gravity measurements at Noranda, Ontario, shows a direct relation between density and the occurrence of ore. This suggests that gravity measurements may be used to indicate the likelihood of ores.

MAGNETIC — GENERAL

550. *The Direction of the Geomagnetic Field in Remote Epochs in Great Britain.*
K. M. Creer, E. Irving & S. K. Runcorn, J. Geomag. & Geoelec., Vol. 6, No. 4, pp. 163-168, 1954.

The results of studies on the remanent magnetism of sediments and lava in Great Britain formed in widely different geological epochs are given.

551. *Aeromagnetic Maps of Nova Scotia.*
Canada Geol. Survey, Dept. of Mines & Tech. Surveys, Geophys. Papers 226-228, 230-242, 1955.

552. *The Mineralogy of Rock Magnetism.*
G. D. Nicholls, Advances in Physics, Vol. 4, No. 14, pp. 113-190, 1955.

This paper gives a very detailed review of the mineralogy of rock magnetism and is supplemented by an extensive bibliography.

553. *On the Comparison of Gravimetric and Magnetic Anomalies in the Sahara.* (In French).
J. Castet & J. Lagrula, Acad. Sci. Paris Comptes Rendus, Vol. 241, No. 1, pp. 84-86, 1955.

Comparison between isostatic anomalies for depth of compensation of 20 km. and vertical magnetic anomalies shows the agreement is marked in some places, but of opposite sign with the positive gravity anomaly corresponding to a negative magnetic anomaly.

(From Geophys. Abstracts 163, U.S. Geol. Survey).

554. *Geomagnetic Campaigns in the Region of the Antarctic Peninsula, the Adjacent Islands and the Weddel Sea, from 1951 - 56.* (In Spanish).
Geofis. Pura e Appl., Vol. 35, No. 3, pp. 40-48, 1956.

The instrumental equipment for these campaigns was modified to meet the extreme conditions. At most points observations were made with both QHM and BMZ magnetometers which were compared at observatory and base stations by means of theodolite and earth inductor.

The results are tabulated and discussed. A map shows observation station locations.

555 *The Use of the Cooling-History of Thick Intrusive Sheets for the Study of the Secular Variation of the Earth's Magnetic Field.*
J. C. Jaeger & R. Green, Geofis. Pura e Appl., Vol. 35, No. 3, pp. 49-53, 1956.

Numerical results are given which show the way in which the Curie temperature moves inwards from the margin during the cooling of a thick intrusive sheet. The time taken to move from the margin to the centre varies as the square of the thickness of the sheet, being about 6,500 years for a sheet 1,000 m. thick on reasonable assumptions as to the thermal properties of the material. This implies that the secular variation of the earth's magnetic field over periods of time of 1,000 years or more may be studied by measuring the directions of magnetisation at a series of points across the thickness of such a sheet.

556. *Measurements at Sea of the Vertical Gradient of the Main Geomagnetic Field during the "Galathea" Expedition.*
J. Espersen, P. Andreasen, J. Egedal & J. Olsen, J. Geophys. Res., Vol. 61, No. 4, pp. 593-624, Dec. 1956.

During the Danish "Galathea" expedition, 1950-52, investigations were made of the vertical gradient of the geomagnetic field, in an attempt to test the probability of the new "fundamental" theory for the main geomagnetic field proposed by P.M.S. Blackett in 1947.

Three relative, self-recording magnetometers are described. All may be lowered to extreme depths in the sea in non-magnetic containers.

In the pacific Ocean, a series of trial measurements were carried out, and at least one of the H magnetometers proved to be of the desired accuracy of 10 γ during a single relative measurement. All trial stations were situated in places with locally disturbed geomagnetic field, which makes the gradient results unreliable, and a breakdown of the technical equipment of the surveying vessel prevented measurements at stations better suited to magnetic work. However, summing up, the trial results indicate a case against the fundamental theory, in accordance with gradient measurements ashore in mines and collieries.

557. *Rock Magnetism.*
S. K. Runcorn, Nature, Vol. 179 (4565), p. 866, 27.5.57.

A short note in criticism of Dr. J. A. Clegg's account of the discussion on "Rock Magnetism" at the recent British Association meeting.

MAGNETIC — INSTRUMENTAL

558. *Recent Developments in Magnetic Prospecting.* (In Japanese with English summary).
Y. Kato, Butsuri-Tanko, Vol. 6, No. 3, pp. 255-264, 1953.

A general discussion on the airborne magnetometer.

559. *Apparatus for the Measurement of the Intensity of the Geomagnetic Field.* (In French).
R. Birebent, Acad. Sci. Paris Comptes Rendus, Vol. 241, No. 4, pp. 368-369, 1955.

A brief description of a magnetometer based on an A-C coil that imposes a torsion on a piezoelectric crystal inducing an alternating tension that can be amplified. The instrument measures both horizontal and vertical components of the magnetic field.

560. *Development of a Vibrating-Coil Magnetometer.*
Rev. Sci. Instr., Vol. 27, No. 5, pp. 261-268, 1956.

The vibrating-coil magnetometer measures the magnetization of a small sample of magnetic material placed in an external magnetizing field by converting the dipole field of the sample into an electrical signal. To allow space for temperature- or pressure-generating apparatus around the sample, the measurement is made at distances up to 2 c.m. from the sample. The measurement is continuous and can be recorded on a chart as a function of time, temperature, crystallographic orientation, or magnetizing field. The present stable sensitivity is such as to provide one percent accuracy for a dipole moment of 8.56×10^{-4} amp-m^2 (the saturation moment at room temperature of a nickel sphere 1.5 m.m. in diameter). (Author's Abstract).

561. *An Innovation to the Geomagnetic Field Balance.*
G. Fanselau, Geophys. Prosp., Vol. 5, No. 1, pp. 9-19, March 1957.

At the Niemegk Observatory geomagnetic balances with torsion ribbons have been constructed for the past few years. They have well known advantages over balances resting on knife edges: greater stability of the zero position, ease of enlarging the measuring range by torsion, no serious damage when the instrument is not clamped. Both H- and Z- balances have proved highly satisfactory. Also a combined H- and Z- balance has been developed. To a certain extent, the torsion ribbon balances can be made insensitive to levelling errors. Torsion wire balances used as zero instruments have not been considered for field measurements for reasons of time saving. They are however being made for laboratory measurements.

MAGNETIC — INTERPRETATION

562. *Instrument for Computing Poisson's Integral and some of its Applications.* (In Russian).
S. P. Kapitsa, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 4, pp. 369-376, 1955.

In both magnetic and gravimetric surveying it is often necessary to recalculate the observed data from one level to another, which involves computation of Poisson's integral, satisfying the Laplace equation controlling the related field pattern. To reduce the numerical work required, an instrument was designed and built in the Geophysical Institute of the Academy of Sciences of the U.S.S.R. The instrument is similar in appearance and handling to Amsler's planimeter, and it determines the numerical value of the integral with an error smaller than that admitted in the initial measurements. The theory of the operation of the instrument is discussed and its use illustrated on several examples.

(From Geophys. Abstracts 163, U.S. Geol. Survey).

563. *The Interpretation of Magnetic and Gravitational Anomalies by the Method of the Exclusion of Elementary Field.* (In Russian).
D. S. Mikov, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 218-225, 1956.

For the interpretation of gravitational or magnetic anomalies of two-dimensional bodies, it is suggested that it be assumed that the disturbing body is composed of a number of prisms of the same density or magnetic properties and filling completely the volume occupied by the body. For every elementary prism it is possible under certain assumptions to evaluate its part in the anomaly; by consecutively subtracting these contributions of individual prisms or combinations of prisms until the total anomaly is exhausted, the shape of the disturbing body is found. Four alinement charts and two tables of numerical values facilitate the procedure.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

564. *Note on the Adjustment of Isomagnetic Charts to Mutual Consistency.*
A. J. Zmuda, J. Geophys. Res., Vol. 61, No. 1, pp. 57 & 58, 1956.

Precise aeromagnetic measurements of total magnetic intensity permit the construction of isomagnetic charts which are mutually consistent in the horizontal and vertical components of the geomagnetic fields. Equations incorporating this new result are provided, (Author's Abstract).

565. *A Method of Interpolating Magnetic Data under Conditions of Mutual Consistency.*
A. J. Zmuda & J. F. McClay, Geophys. Res., Vol. 61, No. 4, pp. 57 & 58, 1956.

Because of the descreteness of the data obtained in magnetic surveys, it is necessary to interpolate between measured points before charts can be drawn. Rigorous relations connecting surface variations of different elements are herein introduced into the interpolation formulae, so that the resulting charts are mutually consistent. Related elements are continued by a power series in which the unknown coefficients are computed under the conditions for consistency.

MAGNETIC — THEORY & RESEARCH

566. *Note on the Adjustment of Isomagnetic Charts to Mutual Consistency.*
A. J. Zmuda, J. Geophys. Res., Vol. 61, No. 1. pp. 57 & 58, 1956.

Precise aeromagnetic measurements of total magnetic intensity permit the construction of isomagnetic charts which are mutually consistent in the horizontal and vertical components of the geomagnetic fields. Equations incorporating this new result are provided. (Author's Abstract).

567. *The Interpretation of Reversed Magnetization in Igneous Rocks.*
J. H. Parry, J. Geomag. & Geoelec., Vol. 6, No. 4, pp. 210-214, 1954.

A review of the various hypotheses on internal self-reversal of permanent magnetization and of the laboratory experiments based on them

568. *Reverse Magnetization of Rocks and its Connection with the Geomagnetic Field.*
T. Nagata, S. Akimoto, S. Uyeda, K. Momose & E. Asami, J. Geomag. & Geoelec., Vol. 6, No. 4, pp. 182-190, 1954.
Palaeomagnetic study by means of the natural remanent magnetization of igneous rocks is reliable only when the natural remanent magnetization is ascertained to be the thermoremanent magnetization acquired when the rocks were first formed. Several experimental methods are given, for examining whether a given natural remanent magnetization can have definite palaeomagnetic significance or not. The results of tests are discussed.

569. *Correlation of Reverse Remanent Magnetism and Negative Anomalies with Certain Minerals.*
J. R. Balsley & A. F. Buddington, J. Geomag. & Geoelec., Vol. 6, No. 4, pp. 176-181, 1954.

570. *Summary of Studies on Rock Magnetism.*
J. Hospers, J. Geomag. & Geoelec., Vol. 6, No. 4, pp. 172-175, 1954.
Abstracts of recent papers by Hospers on the magnetization of Miocene sediments and Lavas are given, followed by a summary of rock magnetism data extending to the Eocene.

571. *Some Theoretical Aspects of Rock Magnetism.*
L. Neel, Advances in Physics, Vol. 4, No. 14, pp. 191-243, 1955.
A theoretical study of the magnetic properties of rocks, supported by an extensive bibliography.

ELECTRICAL

572. *Equipment and Field Techniques of Electrical Prospecting.* (In Japanese with English summary).
J. Suyama, Butsuri-Tanko, Vol. 6, Nos. 3-4, pp. 244-248, 1953.
A general review of apparatus used in electrical prospecting. Some sources of error are discussed.

573. *Ground Resistivity Methods.* (In Japanese with English summary).
T. Kiyono, Butsuri-Tanko, Vol. 6, No. 3, pp. 237-243, 1953.
Developments in electrical prospecting theory during the past 10 years, including methods of interpretation, are reviewed.

574. *Electromagnetic Methods.* (In Japanese with English summary).
N. Makino, Butsuri-Tanko, Vol. 6, Nos. 3-4, pp. 249-254, 1953.
A report on recent studies of field procedures for the electromagnetic galvanic method, giving examples of the calculations of the field produced by direct current in conductors or in the earth, and of experimental results of exploration for conducting veins, buried mine drifts, or wires.
(From Geophys. Abstracts 165, U.S. Geol. Survey).

575. *Geoelectric Determination of Layer Boundaries of a Tertiary Plateau with Quaternary Cover.* (In German).
N. Tarass, Eclog. Geol. Helvetiae, Vol. 47, No. 2, pp. 269-303, 1954 (1955).

576. *Application of Electrical Exploration to the Structure in the Search for Natural Steam at Larderello (Italy).* (In French).
A. Mazzoni & J. J. Breusse, Internat. Geol. Cong., Algiers, 19th Sess., Comptes Rendus, Sec. 15, Fasc. 17, pp. 161-168, 1954.

577. *The Use of Earth Resistivity Tests in the Location of Underground Water in Canterbury.*
I. McKellar & B. W. Collins, Pacific Sci. Assoc., 7th Cong., Proc., Vol. 2, p. 129, 1949 (1953).

578. *Theoretical Study on the Electromagnetic Induction Method, II.*
T. Kiyono, K. Kimura & K. Kobayashi, Butsuri-Tanko, Vol. 7, No. 4, pp. 195-201, 1954.

In this report, the secondary magnetic field produced by a spherical body in the uniform field is obtained from the electromagnetic equations, and the expression for amplitude and phase angle of the secondary field deduced by L. B. Slichter is generalized to the case of a magnetic sphere. The effects of the permeability on the secondary field are discussed, and the existence of the frequency for which the amplitude of the magnetic field takes a minimum value. (Author's Abstract).

579. *The Basic Principles of the Self-Potential Method.* (In German).
F. Wilckens, Zeitschr. Geophysik, Vol. 21, No. 1, pp. 25-40, 1955.

After a discussion of the contradictions in the literature concerning the self-potential method, it is shown that the SP curve measured near ore bodies is due mainly to the potential drop at the ore and electrolyte boundary, an explanation well in accordance with the oxidation-reduction theory. To illustrate, electrochemical processes in the vicinity of graphite deposits are examined in particular. The various methods of measuring the potential drop are reviewed briefly.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

580. *Experiences in the Use of Low-Frequency Earth Currents in Prospecting.* (In Russian).
P. I. Khovanova, Akad. Nauk SSSR Geofiz. Inst. Trudy, No. 30 (157), pp. 272-277, 1955.

The results of electrical measurements in an area where stray currents were intense owing to the proximity of electric railways and other electrical installations. It was possible to measure the potential drop in steps of 10 millivolts over distances of several hundred metres. Areas of decreased p.d. indicate ore-bodies with high electric conductivity.

581. *Two-Coil Reflex Galvanometer Free of Inductive Coupling.* (In Russian).
G. V. Groshevoy, Akad. Nauk SSSR Geofiz. Inst. Trudy, No. 29 (156), pp. 78 & 79, 1955.

Description of a two-coil reflex galvanometer, for measurement of telluric currents by the differential method, which is highly sensitive and unaffected by inductive coupling.

582. *On the 'Elflex' Electrical Method for Direct Exploration for Petroleum.* (In Italian).
A. Belluigi, Ser. Geol. Italia Boll., Vol. 77, No. 1, pp. 131-166, 1955.

The direct e.m. effect of a quasi-stationary single electrode, placed on the horizontal surface of a uniform ground, is calculated. Then the radial component of the electric field is analyzed, considering the dielectric constant of the medium.

583. *A Method of Calibrating the Measuring Instruments for Electrical Prospecting.* (In Russian).
O. M. Barsukov, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 1, pp. 109-111, 1956.

An example is used to illustrate a method of calibrating the measuring instruments for electrical prospecting. The method of least squares is used after determining the instrument readings with several known resistances inserted in the circuits.

584. *The Circular Line Electrode in Equipotential Prospecting.*
L. O. Bacon, Min. Engnrg., Vol. 8, No. 2, pp. 213-216, 1956.

In the circular-line electrode method of equipotential prospecting, one of the energizing electrodes is placed in an ore body of lowering the electrode into a drill hole; the other in a circular-line electrode with a radius of about 700 feet placed on the surface of the ground. Equipotential points are then determined at 25- to 100-foot intervals on the ground surface. The results are interpreted qualitatively.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

585. *New Airborne Geophysical Method.*
Engineering & Mining, J., Vol. 157, No. 3, pp. 84-91, 1956.

Aeromagnetic Surveys, Ltd. are using an aircraft which carries an airborne magnetometer, a scintillation counter, a dual-frequency e.m. system, a strip camera, and a radio altimeter. The e.m. system measures the phase shift of a 400 c. signal and a 2, 300 c. signal. The ratio of the two measurements provides information on the conductivity of the conductor producing the e.m. anomaly.

586. *The Reflex Method of Electrical Exploration.* (In Russian).
D. N. Chetayev, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 210-213, 1956.

Two possibilities of using radio waves in geophysical exploration are pointed out: either by measuring the energy emitted by an antenna and that consumed by the ground in different amounts, which depends on the height of the antenna and the presence underground of electrically conductive bodies; or by varying the frequency of the radio emission and finding the frequency corresponding to the changes in the resistivity of the emission, which determines the depth of the buried conductors.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

587. *Transient Fields of a Vertical Dipole over a Homogeneous Curved Ground.*
J. R. Wait, Canadian J. Phys., Vol. 34, No. 1, pp. 27-35, 1956.

Expressions are derived for the transient fields of a dipole or short vertical antenna on a smooth spherical conducting earth, and energized by a current which is discontinuous in time. When the antenna current is a linear function of time, the radiation field on a flat perfectly conducting earth is of step-function form. The departure from the step shape of the field is due to the finite conductivity and the dielectric constant of the ground, the induction and static fields of the antenna, and the curvature of the earth. For distances greater than 50 km. and times less than 0.1 microsecond following the first arrival of the signal, the curvature of the earth begins to have a marked effect. At distances between 20 and 100 km. the induction field of the source dipole becomes appreciable for times greater than 10 microseconds.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

588. *Radiation Resistance of Dipoles in an Interface between Two Dielectrics.*
J. R. Wait, Canadian J. Phys., Vol. 34, No. 1, pp. 24-26, 1956.

Exact expressions are derived for the radiation resistance of electric and magnetic dipoles located in the plane interface between two semi-infinite lossless dielectrics. For the electric dipole the ratio of the radiation resistance in an interface to the corresponding value in free space is approximately equal to N, the relative refractive index, for N greater than 5. For a vertically oriented magnetic dipole or small loop situated in the interface, the ratio is approximately 2/5 N^3 for values of N greater than 5.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

589. *The Method of Evaluating Electromagnetic Fields Excited in Stratified Media by Alternating Current.* (In Russian).
A. N. Tikhonov & D. N. Shakhsuvarov, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 3, pp. 245-251, 1956.

The solution for an alternating electrical field generated by a dipole in a semispace composed of plane-parallel layers, obtained in a general form by Tikhonov and Makhina, has now been obtained in a form adapted for use with modern computing machines.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

590. *Telluric Current Recording Apparatus.* (In Hungarian).
K. Sebestyen, Magyar Allami Eötvös Lorand Geofiz. Intezet Geofiz. Közlemenyek, Vol. 5, No. 1, pp. 53-63, 1956.

Instruments for recording telluric currents are described in detail. Circuit diagrams and a typical field record are included.

591. *Influence of a Ridge on the Ground Wave.*
A. Murphy & J. R. Wait, J. of Research, Vol. 58, No. 1, pp. 1-5, Jan. 1957.

The problem of a plane wave incident on a semi-elliptical boss on an otherwise perfectly conducting flat ground plane is considered. A solution in terms of elliptic wave functions is obtained. Numerical values of the field on the near and far side of this idealized ridge are given for a base width of about two-thirds of a wavelength and various ellipticity ratios.

592. *Calculation of Guard Electrode Response Curves.*
L. De Witte, K. P. Fournier & H. Tejada - Flores.
Geophysics, Vol. 22, No. 1, pp. 67-74, Jan. 1957.

A new approach to guard electrode theory has been formulated in which the electrode is represented by a series of spheres having the same diameter as the electrode. The boreface and invaded zone boundary are considered to be cylindrical. The current from each sphere is calculated from the condition that all spheres must be at the same potential and the potential distribution is found by superposition of the fields due to the individual currents.

For small drill holes in otherwise homogeneous formations of moderate resistivity the prolate spheroid approximation gives results that are identical with those of the present theory. For larger holes, invaded formations and large resistivity contrasts, the prolate spheroid method is shown to give varying degrees of error in the calculated apparent resistivities.

593. *Propagation of Transient Electromagnetic Waves in a Medium of Finite Conductivity.*
B. K. Bhattacharyya, Geophysics, Vol. 22, No. 1, pp. 75-88, Jan. 1957.

Transient electric and magnetic fields have been calculated for ramp function and sawtooth current sources immersed in a semi-conducting medium. An electric dipole source has been assumed. In the case of ramp function input, it is observed that the peaks of the overshoots in the component of the electric field decrease in magnitude with the increase in rise time of the input pulse. It has also been shown that the rise time of the current pulses has definite effect upon the rise time and amplitude of the electric fields and that the sawtooth exciting pulses having large values of rise time may be conveniently used to obtain measurable values of the electric and magnetic fields.

594. *Can Oil Be Found by Direct Methods.*
F. W. Lee, Oil & Gas J., Vol. 55, No. 13, pp. 109-112, 1.4.57.

The author claims good results in direct oil-finding by the self-potential method. One technique employs electrodes on the surface and down a well; this is called the

'Sandexsurvey' method. A second technique employs surface electrodes only and is called the 'Longcolog' method. Both techniques are based on the large negative potentials carried by oil or gas-impregnated sands. Typical results are shown.

GEOCHEMICAL

595. *Microorganisms and Geochemical Methods of Oil Prospecting.*
G. G. Soli, Bull. A.A.P.G., Vol. 41, No. 1, pp. 134-145, Jan. 1957.

Earlier experiments to determine the hydrocarbon content of soil air and soil itself over known oilfields are briefly described. Soil analysis gives a halo-shaped anomaly of a hydrocarbon concentration above the boundary of the deposit.

Microbiological methods support the soil gas experiments which give a hydrocarbon concentration over the whole of a deposit and not just its boundary. The microorganisms are bacteria which oxidise hydrocarbon gases and breed in them. The relative numbers of bacteria in a sample form a good indicator to hydrocarbon concentration. The state of researches in this method to date is discussed in some detail and it is concluded that microbiological methods can offer a highly efficient prospecting tool.

596. *On the Geochemistry of Uranium in the Baltic Regions.* (In German).
F. F. Koczy, E. Tomic & F. Hecht, Geochim. et Cosmochim., Vol. 11, Nos. 1 & 2, pp. 86-102, Jan./Feb. 1957.

In order to study the geochemistry of uranium on typical shelf zones, samples of river water and sea water, as well as samples of sediment from the Baltic Sea region, have been examined.

The investigation showed that a considerable quantity of uranium is precipitated on the Baltic Sea shelf. It appears to be caused by biological activity in the sea which causes an oxygen deficiency.

RADIOACTIVE

597. *Autoradiographic Determination of Radioactivity in Rocks.*
A. P. Abrahams, Nucleonics, Vol. 15, No. 3, pp. 85 & 86, March 1957.

Geiger-Müller and scintillation counters have two disadvantages. Firstly, shielding to suppress background activity may have to be so bulky as to limit portability; secondly, they can count only one sample at a time.

The autoradiographic method exposes up to 110 samples to the same sheet of film. The unknown samples are compared with samples of known U_3O_8. The method is rated more accurate and more economical than conventional methods.

OTHER METHODS

598. *The Reflex Method of Electrical Exploration.* (In Russian).
D. N. Chetayev, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 2, pp. 210-213, 1956.

Two possibilities of using radio waves in geophysical exploration are pointed out: either by measuring the energy emitted by an antenna and that consumed by the ground in different amounts, which depends on the height of the antenna and the presence underground of electrically conductive bodies; or by varying the frequency of the radio emission and finding the frequency corresponding to the changes in the resistivity of the emission, which determines the depth of the buried conductors.

(From Geophys. Abstracts 165, U.S. Geol. Survey).

TIDAL GRAVITY CORRECTIONS FOR 1958

by

Service Hydrographique de la Marine

and

Compagnie Générale de Géophysique

with an introduction by Jean Goguel

Explanation of the Tables

Tables 1, 2 and 3 give, at hourly intervals, the corrections which must be added to observed gravity values in order to eliminate the disturbing effect of the sun and moon. The factor 1.2 introduced by the elasticity of the earth has been incorporated in the values given in the tables.

The corrections are given in units of a hundredth of a m.gal to the nearest half unit.

Principles of Calculation

It has been shown (Goguel, 1954)* that the correction can be expressed as

$$c = P + N \cos \varphi (\cos \varphi + \sin \varphi) + S \cos \varphi (\cos \varphi - \sin \varphi)$$

The first term P (the correction required at the pole) is always negative and varies very slowly (see Table 1). If only the difference in correction values at intervals of several hours is required, as is often the case in gravimetric prospecting, this term (P) can be ignored.

The terms N and S are the corrections at latitude 45° N and 45° S respectively when P is ignored. At any other latitude φ they must first be multiplied by the coefficient, the numerical values of which are given below and then added.

Lat.	0	5°	10°	15°	20°	25°	30°	35°
Coeff. of N	1	1.08	1.14	1.18	1.20	1.20	1.18	1.14
Coeff. of S	1	0.90	0.80	0.68	0.56	0.44	0.32	0.20

Lat.	35°	40°	45°	50°	55°	60°	65°	70°
Coeff. of N	1.14	1.08	1	0.90	0.80	0.68	0.56	0.44
Coeff. of S	0.20	0.09	0	—0.08	—0.14	—0.18	—0.20	—0.20

In southern latitudes the values of the coefficient of N and S must be interchanged.

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* Goguel, Jean, 1954. A universal table for the Prediction of the Lunar-Solar Correction in Gravimetry (Tidal Gravity Correction). Geophysical Prospecting, Vol. II, Suppl., March.

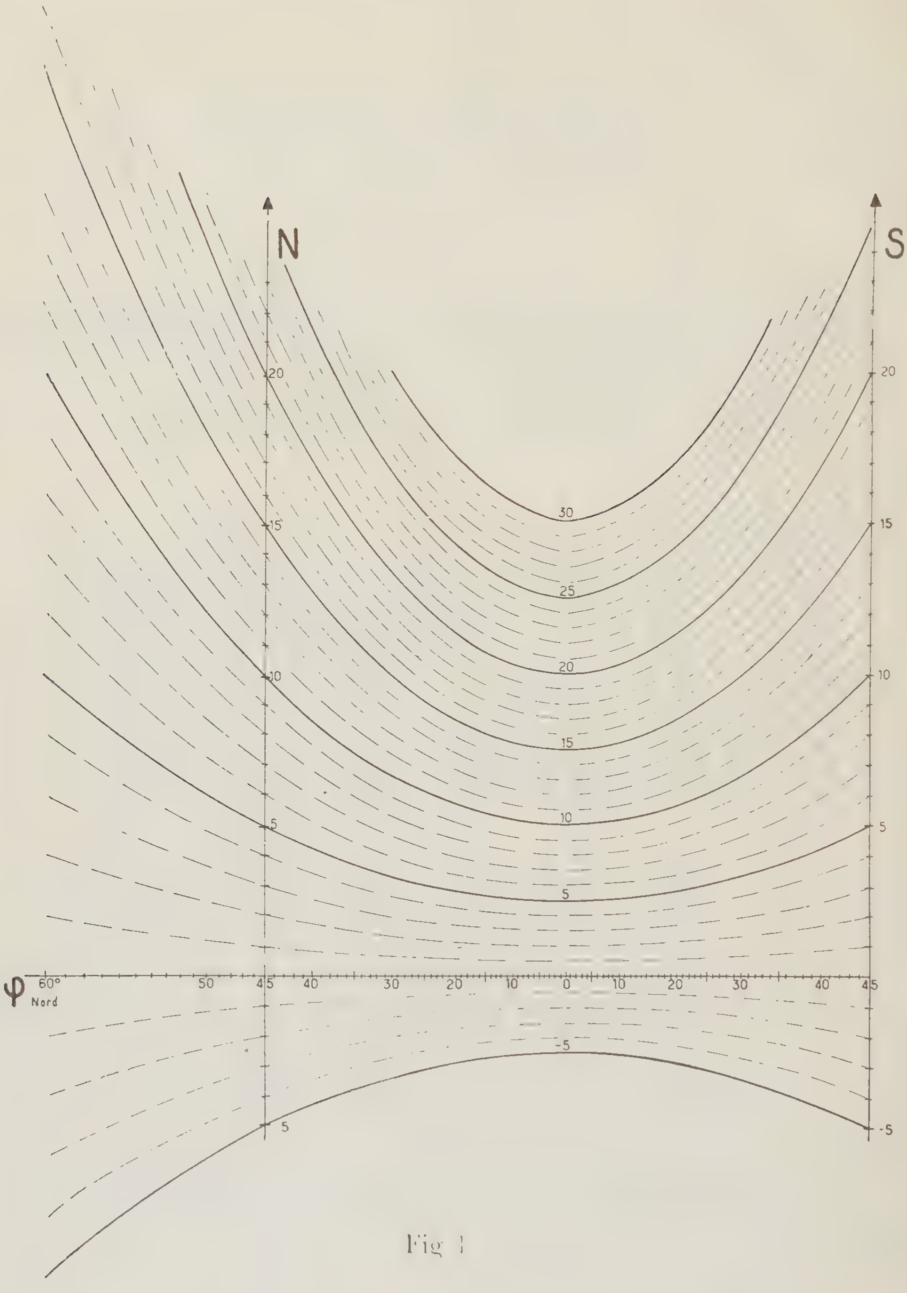

Fig 1

Graph

The value of the correction at latitude φ when P is ignored, can be found from the graph shown in Fig. 1. The intersection of the vertical line through φ with a straight line joining appropriate values of N and S gives the required value.

The procedure is illustrated by Fig. 2. Suppose that the values of N and S, as obtained from the table, are 13 and 3 respectively. Suppose that the latitude of the station is 33° 30′. Connect the point N = 13 and the point S = 3 by a straight line. Determine the point of intersection of this line with the vertical line corresponding to a latitude of 33° 30′. At this point of intersection the curved lines of the graph indicate a value of 15.5. This is the value of the correction (excluding the term P).

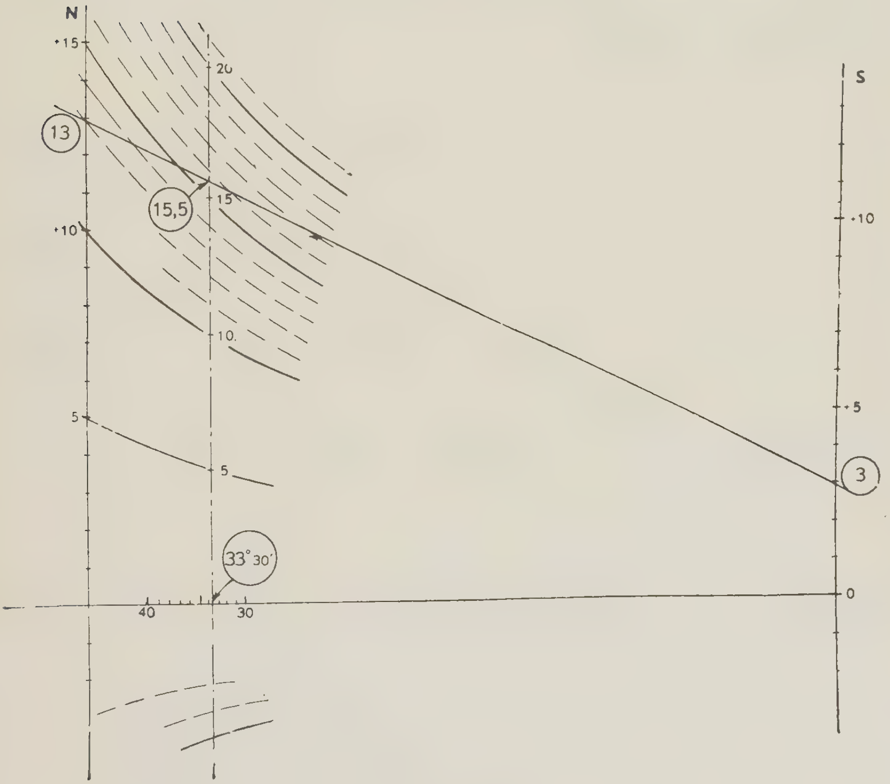

Fig. 2.

Effect of Longitude

Tables 2 and 3 were calculated for the meridians 15° E and 75° W of Greenwich and for the times corresponding to these meridians. They can also be used for the opposite meridians, i.e. 165° W and 105° E of Greenwich respectively, by interchanging the values of N and S. The form of the tables indicates which of the two must be used.

The tables can be used to cover wide areas on both sides by applying the local time at the observation point. Often it will be quite sufficient to take the time of the Central Meridian of the time zone (take care to allow for summer time). If greater accuracy is desired, add to the civil time 4 minutes for each degree east of the Central Meridian of the time zone and subtract 4 minutes for each degree to the west.

Table 2 can thus be used for longitudes ranging from 45° W to 75° E (covering Europe, Africa and the Near East), and for longitudes ranging from 135° E to 105° W. Table 3 can be used for longitudes ranging from 15° W to 135° W (covering the American continent), and for longitudes ranging from 45° E to 165° E (covering the Far East). The error in the value of the correction caused by this extension is always less than 0.01 mgal.

Table 1 can be used for all longitudes.

TABLE 1

Values for P given in hundredths of a milligal

1958	Jan.	Febr.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	1958
1	5½			9½	9			7			6	7	1
2		7	8			6	6		7½	6½			2
3	5½			10	8			7½			7½	8	3
4		8½	9½			6	6½		6½	6½			4
5	6			9	7			7			8½	8½	5
6		9	10			6	7		6½	7½			6
7	7½			8	6½			6			9	8	7
8		9	9½			6½	6½		7	8½			8
9	8½			7	6½			6			8½	7	9
10		8	8			6½	6		8½	9½			10
11	8½			7	7			6½			7½	6	11
12		7	7½			6	5½		9½	9½			12
13	8			7½	7½			7½			6½	6	13
14		6½	7			5½	5½		10	8½			14
15	6½			8	7			9			6½	6½	15
16		7	7½			5	6½		9	7½			16
17	6			7½	6			9½			7	7	17
18		7½	8			6	8		8	7			18
19	6			7	5½			9			7½	6½	19
20		8	8			7	8½		7½	7½			20
21	6½			6½	6			8			7	5½	21
22		7½	7½			8	8½		7½	8			22
23	7			6½	7			7			6½	5	23
24		7	7			8½	7½		8	8			24
25	7			7½	8			7			5½	5	25
26		6½	6½			7½	6½		8½	7½			26
27	6½			8½	8½			7½			5	6	27
28		7	7½			6½	6½		8	6½			28
29	6			9½	8			8			6	7½	29
30			9			6	6½		7	6			30
31	6				7			8				8	31

Table 2

Month: January 1958

		0 h.		1 h.		2 h		3 h.		4 h.		5 h		6 h.		7 h.		8 h		9 h		10 h.		11 h				
		12 h.		13 h.		14 h.		15 h		16 h.		17 h.		18 h.		19 h.		20 h		21 h.		22 h		23 h.				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W	Dates East of 180	Dates West of 180
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S			
Dates 1	AM	9 ½	1	7	2	4 ½	−2	2 ½	1	1 ½	1	1	4 ½	1	8	1 ½	11	2	13 ½	2	15	1	15	0	13 ½	PM		1
	PM	1	11	−2	8	−2 ½	5	−1 ½	2 ½	0	1	3	0	6 ½	0	10 ½	½	13	1	15 ½	1 ½	16	1	15	½	AM	1	2
2	AM	12 ½	−1	9	2	6	−2 ½	2 ½	2 ½	0	−1	−1	2	−1	5 ½	−½	9 ½	½	13	1	16	1	17	½	16 ½	PM		
	PM	−½	14	−2	11	−3	7	−3	3	−2	½	½	−1	4 ½	−1 ½	9	1	13	½	16	½	17 ½	1	17 ½	½	AM	2	3
3	AM	15 ½	½	12	−2	8	3	4	−3 ½	½	−3	−1 ½	−1	2 ½	3	−2	7	−1	12	0	15 ½	½	18	½	18 ½	PM		
	PM	0	17	−1 ½	14	−3	10	−4	5	−3 ½	1	−2	−1 ½	1 ½	3	6	−3	11	−2	15	−½	18	½	19 ½	1	AM	3	4
4	AM	18	0	15 ½	−1	11	3	6	−4	2	−4	−1 ½	−2 ½	−3	1	3 ½	5	−2 ½	10	1	15	0	18	1	20	PM		
	PM	½	19	−½	16 ½	−2	12	−3 ½	7	−4 ½	2 ½	3 ½	−1	−1	−3	3	−3 ½	8	−3 ½	13	1 ½	17 ½	0	20	1	AM	4	5
5	AM	20 ½	1	18 ½	0	14 ½	−1 ½	9 ½	3	4 ½	−4 ½	0	−4	−2 ½	−2	−4	2	−3 ½	7	−2	12	0	17	1	20	PM		
	PM	1 ½	21	1	19	½	15 ½	−2 ½	11	4	5 ½	−4	1	−3	2	0	4	4 ½	−3 ½	10	2 ½	15	½	19	1	AM	5	6
6	AM	20 ½	2	20 ½	1 ½	18	½	13 ½	1 ½	8	−3	3	−4	−1	−3	3 ½	−1	−4	3 ½	3	8 ½	−1	14	1	18	PM		
	PM	2	20	2 ½	20 ½	1 ½	18	0	14	−2	9	−3 ½	4	3 ½	−½	−2	3	1 ½	−3 ½	6 ½	−3	11 ½	−2	16	1	AM	6	7
7	AM	19 ½	3	20 ½	3 ½	19	2 ½	15 ½	1	11	−1	5 ½	3	1	3 ½	−2	−2	−3 ½	1	−3	5	−1	10	1	15	PM		
	PM	3	18 ½	4	20	3 ½	19	2 ½	16	½	11 ½	−1 ½	6 ½	−2 ½	2	−2	1 ½	0	−3	3 ½	3	8	−1 ½	13	1	AM	7	8
8	AM	16 ½	3	19	4 ½	19	4 ½	17	3 ½	13	2	8 ½	0	4	−1 ½	0	−2	2	0	−2 ½	2 ½	−1 ½	6 ½	½	11	PM		
	PM	2 ½	15	4 ½	17 ½	5 ½	18	5	17	3 ½	13 ½	1 ½	9	0	5	−1	1	½	1 ½	1 ½	−2 ½	5	1 ½	9	0	AM	8	9
9	AM	13	2 ½	15 ½	5	17	6	16 ½	6	14 ½	5	10 ½	3 ½	6 ½	1 ½	2 ½	½	−½	0	−2	1 ½	−2	4	0	7	PM		
	PM	2	11	4 ½	14	6	15 ½	7	15 ½	6 ½	14	5	10 ½	3 ½	7	2	3	1	0	1 ½	1 ½	3	1 ½	6	½	AM	9	10
10	AM	9	2	12	4 ½	14	6 ½	14 ½	7 ½	13	7 ½	10 ½	6 ½	7 ½	5	4	3 ½	1	2 ½	−1	2	−1 ½	3	½	5	PM		
	PM	1 ½	7 ½	4	10	6	12	7 ½	12 ½	8 ½	12	8	10	7	7 ½	5 ½	4	4	1 ½	3 ½	½	3 ½	−1	4 ½	−½	AM	10	11
11	AM	6	1	8	3	10	6	11	8	11	9	10	9 ½	7 ½	8 ½	5	7 ½	2	6	0	4 ½	−1	4	−1	4 ½	PM		
	PM	0	5	2	6 ½	5	8	7	9	9	9 ½	10	8 ½	10	7	9	5	8	2 ½	6 ½	½	5 ½	1	4 ½	1	AM	11	12
12	AM	4 ½	0	5 ½	1 ½	6 ½	4	7	6 ½	7 ½	9	7 ½	10 ½	6 ½	11	5	11	3	10	1	8	½	7	−1	5 ½	PM		
	PM	−½	5	½	4 ½	3	5	5 ½	5 ½	8	6	10 ½	6	11 ½	5 ½	12	4	11 ½	2 ½	10	1	8 ½	0	7	1	AM	12	13
13	AM	5	−1	4 ½	0	4	2 ½	4	5	4	8	4 ½	10 ½	4	12	3 ½	13	2 ½	13	1	12	0	10	−1	8	PM		
	PM	−1	6	−½	4	1	3	3 ½	2 ½	6 ½	2 ½	9 ½	3	12	3	13 ½	2 ½	14	2	13 ½	1	12	0	10	1	AM	13	14

15	AM	10	-1½	7	-2	4	-1½	1½	0	0	2½	-1	5½	-½	9½	0	13	0	15½	½	16½	0	16½	-½	14½	PM	14	15
	PM	-1	12	-2	8	-2	4½	-1	1½	1	-½	4	-1½	7½	-1½	11½	-1	15	½	17	0	17½	½	16	0	AM	15	16
16	AM	13	-1	9½	-2	5½	-2½	2	2	½	0	-2	3	2½	6½	-2	10½	-1	14½	0	17	½	18	0	17	PM		
	PM	-1	14½	-1½	11½	-2½	7	-2½	3	-1	-½	1½	-2	5	-3	9½	-2½	13½	-1½	16½	-½	18	½	18	½	AM	16	17
17	AM	16	0	12½	-1	8	-2½	4	-3	0	-2	-2	0	-3	3½	-3	7½	-2	12	-½	15½	½	18	1	18½	PM		
	PM	0	17	-1	14	-2	10	-3	5	-2½	1	-1	-2	2	-3	6	-3	10½	-2½	15	-1	17½	½	19	1	AM	17	18
18	AM	18	1	15	0	11½	-1½	7	2½	2½	-3	-1	-2	-3	½	-3½	4	-2½	9	-1	13	½	17	1½	19	PM		
	PM	1½	18½	1	16½	-½	12½	-2	8	-3	3½	-2	0	½	-3	3	3½	7½	-3	12	-1	16	½	18½	2	AM	18	19
19	AM	19	2½	17	1½	13½	0	9	-1½	4½	-2½	½	-2½	-2	-1	3	2	-2½	6½	-1	11	½	15	2	18	PM		
	PM	3	18½	2½	17	1	14	-½	10	-2	5	-2½	1	-1½	-2	1	3	5	-2½	9½	-1	13½	1	17	2½	AM	19	20
20	AM	18½	3½	18	3½	15½	2	11	½	6½	-1	2½	-2	-1	-1½	-2½	½	-2½	4	-1	8	½	12½	2½	16	PM		
	PM	4	18	4½	17½	3½	15½	1½	12	0	7	-1½	3	-1½	0	0	-2	3	2½	7	-1	11	1	14½	3	AM	20	21
21	AM	17	4½	18	5	16	4½	13	2½	9	1	4½	-½	1	-1	1½	0	-2	2½	-1½	6	½	10	3	13½	PM		
	PM	4½	16	5½	17	5½	16	4	13	2	9	½	5	½	1	0	-1	1½	2	5	-1	8½	½	12	3	AM	21	22
22	AM	15½	5	16½	6	16	6	13	5	9½	3	5½	1	2	0	-½	½	-1½	2	-1	4½	½	8	3	11½	PM		
	PM	5	14½	6½	16	7	15½	6	13½	4	10	2½	6	1	2½	1	0	2	-1½	4	-1	7	½	10½	3	AM	22	23
23	AM	13½	5	15	6½	15	7½	13½	7	10½	5½	7	3½	3½	2	1	1½	-1	2	-1	3½	0	6	2½	9½	PM		
	PM	5	12	6½	14	7½	14½	7½	13	6½	10½	5	7½	3½	4	2½	1	2½	-½	3½	-1	5½	0	8½	2	AM	23	24
24	AM	11	4½	13	6½	13½	8	13	8	11	7½	8	6	4½	4½	2	3½	0	3	-½	3½	0	5	1½	7½	PM		
	PM	4	10	6	11½	8	12½	8½	12	8	10	7	7½	5½	4½	4½	2	4	0	4	-½	5	0	7	1	AM	24	25
25	AM	9	3½	10½	6	11½	7½	11½	8½	10	8½	8	8	5	6½	2½	5½	½	4½	½	4½	-½	5	1	6½	PM		
	PM	3	8	5	9½	7	10½	8½	10½	9	9	8½	7	7½	5	6½	2½	5½	½	5	½	5½	-½	6	½	AM	25	26
26	AM	7	2½	8½	4½	9	6½	9½	8	8½	9	7	9	5	8½	3	7½	1	6½	0	6	-½	5½	0	6	PM		
	PM	1½	6½	3½	7½	6	8	7½	8	9	7½	9½	6½	9½	4½	8½	3	7½	1	7	0	6	-1	6	0	AM	26	27
27	AM	6	1	6½	3	7	5	7	7	7	9	6	9½	4½	10	3	9½	1	8½	0	7½	-½	7	-½	6	PM		
	PM	½	6	2	6	4	6	6	6	8	5½	9½	5	10½	4	10½	2½	10	1	9	0	8	-1	7	-1	AM	27	28
28	AM	6	0	5½	1½	5	3½	5	6	4½	8	4	9½	3½	11	2½	11½	1	11	0	10	½	9	-1	7½	PM		
	PM	½	6	½	5	2½	4½	4½	4	7	3½	9	3	11	2½	12	2	12	1	11½	0	10	½	8½	-1	AM	28	29
29	AM	7	-1	5	0	4	1½	3	3½	2½	6	2½	8½	2	10½	1½	12	1	13	½	12½	-½	11½	-1	9½	PM		
	PM	-1½	7½	-1	5½	½	3½	2	2½	5	1½	7½	1	10½	1	12½	1	13½	½	14	½	13	-½	11	-1	AM	29	30
30	AM	9	-1½	6	-1½	4	-½	2	1	1	3½	½	6½	½	9½	½	12	½	14	½	15	0	14	-1	12½	PM		
	PM	1½	10	-2	7	-1	4	0	1½	2	0	5	-½	8½	-½	12	0	14½	½	16½	½	15½	0	14½	½	AM	30	31
31	AM	11½	-1½	8	-2	5	-2	2	-1	0	1½	-1	4½	-1	8	-½	12	½	15	1	16½	½	17	0	15½	PM		
	PM	1	12½	-2	9	-2½	5	-1½	2	0	0	2½	-1½	6½	-1½	10½	-1	14	0	17	1	18	1	17	½	AM		

Table 2

Month: February 1958

		0 h.		1 h.		2 h.		3 h.		4 h.		5 h.		6 h.		7 h.		8 h.		9 h.		10 h.		11 h.				
		12 h.		13 h.		14 h.		15 h.		16 h.		17 h.		18 h.		19 h.		20 h.		21 h.		22 h.		23 h.				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W	Dates	
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		East of 180°	West of 180°
Dates 1	AM	15	−½	11	−1½	7	−2½	3	−2½	0	−1	−1½	1½	−2	5	−1½	9½	0	14	1	17	1½	18½	1½	18	PM		1
	PM	½	16	−1	12½	−2	8	−3	3½	−2	0	0	−2	3	−2½	7½	−2	12	−½	16	1	18½	2	19½	2½	AM	1	2
2	AM	18	1½	15	0	10½	−2	5½	−3	1½	−3	−1½	−1	−2½	2	−2½	6	−1	11	1	15½	2½	18½	3	20	PM		
	PM	2½	19	1½	16	−1	11½	−2½	6½	−3	2	−2½	−1	0	−2½	4	2½	9	−1	14	1	17½	3	20	4	AM	2	3
3	AM	20	3½	17½	2½	13	0	8½	−2	3½	−3	−½	−3	−2½	−1	−2½	3	−1½	8	1	13	3	17½	4½	20	PM		
	PM	5	20	4	18	1½	14	−1	9	−2½	4	−3	0	−2	−2	1	−2½	5½	−1½	11	1	15½	3	19	5	AM	3	4
4	AM	20½	6	19½	5	16	3	11½	½	6	−2	1½	−3	−1½	−2½	−2½	0	−2	4	0	9	3	14	5½	17	PM		
	PM	6½	20	6½	19½	5	17	2½	12½	0	7	−2	2½	−2½	−1	−1	−2½	2	−2	7	0	11½	3	16	5½	AM	4	5
5	AM	19	7½	19½	8	18	6½	14	4	9	1	4½	−1	½	−2½	−2	−1½	−2	1	−½	5	2	9½	5½	14½	PM		
	PM	7½	17½	8½	18½	8	18	6	14½	3	10	½	5	−1½	1	−1½	−1½	0	−2	3½	−½	7½	2	12	5	AM	5	6
6	AM	16	8	17½	9½	17	9	14½	7½	10½	4½	6	1½	2	−½	−1	−1½	−1½	0	−1	2½	2	6½	5	11	PM		
	PM	8	14½	10	15	10½	15½	9	14½	6½	11	3½	6½	1	2½	0	0	0	−1½	1½	−1	5	1½	8½	4½	AM	6	7
7	AM	12	8	14½	10	15	11	14	10½	11	8½	7	5½	3½	3	½	1	−1	½	−1	1	½	3½	3½	6½	PM		
	PM	7	10	9½	12½	11½	13½	11½	13	10	11	7½	7½	5	4	2½	1	1½	−1	1½	−1	3	0	5	3	AM	7	8
8	AM	8	6	10½	9	12	11	12	12	10½	11½	8	9½	4½	7	2	4½	−½	2½	−1	2	0	2½	2	4	PM		
	PM	5	6	8	8½	11	10	12	10½	12½	9	11	7	9	4½	6½	2	4½	0	3	−1	3	−½	3½	1	AM	8	9
9	AM	5	4½	7	7½	8	10½	8½	12	8	12½	6½	12	4½	10	2	8	0	6	−½	4	−½	3½	½	3½	PM		
	PM	3	4	6	5½	9	6½	11	7	12½	6½	13	5½	12	4	10	2	8	½	6	−1	4½	−1	4	½	AM	9	10
10	AM	3½	2½	4	5	5	8	5½	10½	5½	12	5	13	3½	12½	2	11½	½	9½	−½	7½	−1	6	−½	4½	PM		
	PM	1	4	3½	3½	6½	3½	9	4	11½	4	13	3½	13½	2½	13	1½	11½	½	10	−½	8	−1	6	−½	AM	10	11
11	AM	4½	½	3½	2½	3	5	2½	8	2½	10	2½	12	2	13½	1½	13½	1	13½	0	11½	½	9	−½	7	PM		
	PM	0	5	1½	3	3½	2	6	1½	8½	1½	11	1½	13	1	14	1	14	½	13	0	11	0	9	−½	AM	11	12
12	AM	6	0	4	1	2	2½	1	5	½	7½	½	10½	½	12½	½	14	½	14½	½	14	0	12	−½	10	PM		
	PM	−½	7	0	4½	1½	2	3½	½	6	0	8½	−½	11½	0	13½	0	15	−½	15	−½	14	0	12	0	AM	12	13
13	AM	9	−½	6	0	3	½	1	2	−½	4½	−1	7½	−1	10½	−½	13	½	15	½	15½	1	15	½	13	PM		
	PM	0	10	−½	7	0	3½	1	½	3	−1	5½	−1½	9	−1½	12	−½	14½	0	16	1	16	1½	14½	1	AM		

15	AM	14 2	11 ½	7 0	3 −½	0 0	−1½ 2	−2 5	−1 8	½ 12	2 15	3 17	3 17	PM	14	15
	PM	2½ 15	1½ 12	½ 8	−½ 4	−½ ½	1 −1	3½ −2	7 −1	11 ½	14 2	16½ 3½	17 4	AM	15	16
16	AM	16 3½	13 2½	9 1	5 0	1½ −1	−1 0	−1½ 2	−1 5½	½ 9½	2 13	4 16	5 17	PM		
	PM	5 16½	3½ 14	2 10	0 6	−½ 2	−½ 0	1 −1½	4½ −1	8½ ½	12 2½	15 4½	17 6	AM	16	17
17	AM	17 6	15 5	11½ 3	7½ 1	3½ −½	½ −½	−1 ½	−1 3	½ 7	2½ 10½	5 14	6½ 16½	PM		
	PM	7 17	6 15½	4 12	2 8	0 4	−½ 1	0 −1	2 −1	6 0	10 2½	13½ 5	16 7	AM	17	18
18	AM	17 7½	15½ 7	12½ 5	9 3	5 1	1½ −½	−½ 0	−1 2	½ 5	2½ 9	5 12½	7½ 15½	PM		
	PM	8½ 16½	8 15½	6½ 13	4 9	2 5	0 2	0 0	1 −½	4 ½	7½ 2½	11½ 5½	14½ 8	AM	18	19
19	AM	16 9	16 9	13½ 7½	10 5	6 2½	2½ 1	0 0	−½ 1	0 3	2 6½	5 10	7½ 13½	PM		
	PM	9½ 15½	10 15½	8½ 13½	6½ 10½	4 6½	1½ 3	½ ½	1 −½	2½ 0	[illegible]½ 2	9 5	12½ 7½	AM	19	20
20	AM	14½ 9½	15 10½	14 9½	11 8	7½ 5	4 2½	1 1	0 1	0 2	1½ 5	4½ 8	7½ 11	PM		
	PM	9½ 13½	11 14½	10½ 13½	9 11	6½ 7½	3½ 4	2 1½	1 0	2 0	4 1½	7 4	10 7	AM	20	21
21	AM	12½ 10	13½ 11	13 11	11 9½	8 7	4½ 4½	1½ 2½	0 1½	0 2	1 4	3½ 6½	6½ 9	PM		
	PM	9½ 11½	11 12½	11½ 12½	10½ 10½	8½ 8	5½ 4½	3½ 2	2 0	2 0	3½ 1	5½ 3½	8 6	AM	21	22
22	AM	10½ 9	12 11	12 12	10½ 11	8 9	5 7	2 4½	½ 3	0 2½	½ 3	2½ 5	5½ 7	PM		
	PM	8½ 9	10½ 10½	11½ 11	11½ 10	10 7½	8 5	5½ 2	4 ½	3 ½	3 0	4 2	6 5	AM	22	23
23	AM	8 7½	9½ 10	10 11½	9½ 11½	7½ 11	5 9	2½ 7	½ 5	½ 3½	0 3½	1½ 4	4 5½	PM		
	PM	6½ 7	9 8½	11 9	11½ 8	11 7	10 5	[illegible] 2½	6 ½	4½ ½	4 ½	4 1	5 3	AM	23	24
24	AM	6 6	7½ 8½	8 11	7½ 11½	6½ 11½	4½ 10½	2½ 9	½ 7	−½ 5½	−½ 4½	½ 4	2½ 4½	PM		
	PM	5 5½	7½ 6½	10 6½	11½ 6½	12 5½	11 4	10 2	8 ½	6½ −½	5 ½	4½ 0	4½ 2	AM	24	25
25	AM	5 4	5½ 7	6 9	5½ 11	5 11½	3½ 11½	2 10½	1 9½	½ 7½	1 6	½ 5	1 4½	PM		
	PM	3 4½	5½ 4½	8 4½	10 4½	11½ 4	12 3	11½ 2	10½ ½	9 0	7½ −1	6 ½	5 ½	AM	25	26
26	AM	4½ 2½	4 4½	4 7	3½ 9	3½ 11	2½ 12	2 12	1 11½	0 10½	−½ 9	−½ 7	0 5½	PM		
	PM	1½ 4½	3 4	5½ 3	8 3	10 2½	11½ 2	12½ 1½	12½ ½	11½ 0	10 ½	8½ ½	7 0	AM	26	27
27	AM	5 1	4 2½	3 5	2 7	2 9½	1½ 11½	1 12½	1 13	½ 12½	0 11½	−½ 9	−½ 7½	PM		
	PM	½ 5½	1½ 4	3 2½	5½ 1½	8 1	10½ 1	12½ 1	13½ 1½	14 ½	13 ½	11½ 0	9½ 0	AM	27	28
28	AM	7 0	4½ 1	3 2	1½ 4	½ 7	½ 9½	½ 12	1 14	1 14½	1 14	½ 13	0 10½	PM		
	PM	0 8	0 5	1 2	2½ 1	5 0	8 0	11 ½	13½ 1	15 1½	15½ 2	14½ 1½	13 1	AM	28	29
29	AM													PM		
	PM													AM	29	30
30	AM													PM		
	PM													AM	30	
31	AM													PM		
	PM													AM		

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Month March 1958

		0 h.		1 h.		2 h		3 h.		4 h.		5 h.		6 h.		7 h.		8 h		9 h.		10 h		11 h				
		12 h.		13 h.		14 h		15 h.		16 h		17 h		18 h		19 h		20 h		21 h		22 h		23 h				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W	Dates	
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		East of 180	West of 180
Dates 1	AM	10	½	7	0	4	½	1½	1½	0	3½	½	6½	0	10	1	13	2	15½	2½	16	2½	16	2	14	PM		1
	PM	1	11	0	7½	0	4	½	1½	2	0	4½	1	8	0	11½	1	14½	2½	16½	3½	17	3½	16	3	AM	1	2
2	AM	13	2	9	½	5	½	2	½	0	1	-1	3½	-½	7	1	11	2½	14½	4	17	4½	18	4	16½	PM		
	PM	3	14	1½	10	0	6	-1	2½	½	0	1½	-1	5	½	9	1	13	3	16½	5	18	6	18	5½	AM	2	3
3	AM	16	4½	12½	2½	8	½	4	-1	½	1	-1	½	-1	3½	½	7½	3	12	5	15½	6½	18	7	18½	PM		
	PM	6	17	4	13½	1½	9	-½	4½	-1½	1	-1	-1	1½	-1	5	½	9½	3	14	5½	17	7½	18½	8½	AM	3	4
4	AM	18	18	15	6	11	3	6	0	2	1½	½	-2	1½	0	0	3½	2	8	5	12½	8	16	9½	18	PM		
	PM	9½	18	8	16	5	12	2	7	-1	2½	-2	0	-1	-1½	1½	½	5½	2	10½	5½	14½	8½	17½	10½	AM	4	5
5	AM	18	11	16	9	12½	6	8	3	4	0	½	2	-1	1½	1	½	1½	4½	5	9	8½	13½	11	16½	PM		
	PM	12	17½	11	16½	8½	13	5	8½	1½	4	-1	½	2	-1	-1	-1	2	1	6½	5	11	8½	14½	11½	AM	5	6
6	AM	16½	13	16½	12½	14	10½	10	7	5½	3	2	0	½	-2	-1	1½	½	1	4	5	7½	9	11	13	PM		
	PM	13½	15½	14	15½	12½	13½	9	10	5	6	1½	2	-1	½	1½	-1	½	0	2½	3	6½	7	10½	11	AM	6	7
7	AM	13½	14	14½	15	13½	14	11	11	7	7	3	3	0	0	-1	-1	½	-1	2	1½	5½	5	10	8½	PM		
	PM	13½	11½	15	13½	15½	12½	13	10½	9½	7	5½	3½	2	½	0	1	½	½	½	1½	3	5	6½	9	AM	7	8
8	AM	10	13	11½	15½	11½	15½	10	14	7½	10½	4	7	1	3	½	½	-1	0	1	½	4	2½	8	5	PM		
	PM	12	8	14½	10	16	10	15	9	12½	6½	9	3½	5½	1	2½	½	1	1	½	½	1½	3½	3½	7	AM	8	9
9	AM	6	11	8	14	8½	16	8	15½	6½	13½	4	11	1½	7½	0	4	-1	2	0	1	2	1½	5½	2½	PM		
	PM	9	4½	12½	6	15	7	15½	7	15	5½	12½	4	9½	1½	6½	0	3½	-1	2	½	1½	1½	2	4½	AM	9	10
10	AM	3	8	4½	11½	5½	14	6	15	5	15	3½	13½	2	11	½	8	[illegible]	5	½	3	½	2	3	2	PM		
	PM	6	2½	9½	3	12½	4	14½	4½	15	4	14½	3	12½	1½	10	½	7	½	5	½	3	½	2½	2½	AM	10	11
11	AM	2	5½	2½	8½	3	11	3	13½	3	14½	2½	14½	1½	13	½	11	0	9	½	6	½	4	2	3	PM		
	PM	4	2	6½	2	9½	2	12	2	13½	2	14	2	13½	1½	12½	1	10½	0	8	0	6	½	4	1½	AM	11	12
12	AM	2½	3	2	5½	1½	8	1½	10½	1½	12½	1½	13½	1	14	1	13	½	11½	½	9½	½	7½	1	5	PM		
	PM	2½	3	4	2	6½	1	8½	½	11	½	12½	½	13½	1	13½	1	13	1	11	1	9	1	6½	1½	AM	12	13
13	AM	4½	2	2½	3	1	5	½	7	0	9	0	11	½	13	1	13½	1½	13½	1½	12½	1½	10½	1½	8	PM		
	PM	2	5½	2½	3	4	1	5½	0	7½	½	10	0	12	½	13	1	13½	1½	13	2	12	2	9½	2	AM		

15	AM	9 3	6 2½	3 2	1 2½	−½ 4	−½ 6	½ 8	1½ 11	3 13	4 14	5 14	4½ 12½	PM	14	15
	PM	4 10	3 7	2 4	2 1	3 0	4½ −½	7 0	10 1½	12½ 3½	14 5	14½ 6	13½ 5½	AM	15	16
16	AM	11 5	8 3½	5 2½	2 2	0 2	−½ 3	½ 5½	2 8½	4 11	5½ 13½	6½ 14½	7 13	PM		
	PM	6 12	4½ 9	3 5½	2 3	1½ ½	2½ 0	4½ ½	7½ 2	10½ 4	13 6	14½ 7½	14½ 8	AM	16	17
17	AM	13 7	10 5½	7 3½	3½ 2	1 1½	0 2	½ 3½	2 6½	4 10	6½ 12½	8 14	9 14½	PM		
	PM	8½ 13	7 10½	4½ 7	2½ 4	1 1½	1 0	2½ ½	5 2	8 4½	11½ 7	13½ 9	14½ 10½	AM	17	18
18	AM	14 9½	11½ 8	8½ 5½	5 3	2 1½	½ 1	½ 2	1½ 4	4 7	7 10½	9½ 13	11 14	PM		
	PM	10½ 14	9 12	7 8½	4 5	2 2	1 ½	1 ½	3 1½	6 4	9 7	12 10	14 11½	AM	18	19
19	AM	14 12	12½ 10½	9½ 8	6½ 5	3 2½	1 1	½ 1	1 2½	3½ 5	6½ 8	9½ 11	12 13	PM		
	PM	12½ 13½	11½ 12½	9 10	6 6½	3½ 3	1½ 1	½ ½	1½ 1	4 3½	7 6½	10 9½	12½ 12	AM	19	20
20	AM	13½ 13	12 12½	9½ 10	6½ 7	3½ 4	1 1½	½ ½	1 1	3½ 3½	6½ 6	10 9	12½ 12	PM		
	PM	13½ 13	13 12	11 10	8 7	5 4	2 1	1 0	1 ½	2½ 3	5½ 6	8½ 9½	11 12	AM	20	21
21	AM	12 14	12 14	10 12	7 9	4 6	1½ 3	0 1	½ 1	2½ 2	5 4	9 7	12 9½	PM		
	PM	14 11	14½ 11	13 10	10 7½	7 4	3½ 1½	1½ 0	1 0	1½ 1½	3½ 4½	6 8	8½ 11	AM	21	22
22	AM	10 14	10½ 14½	9½ 14	7 11½	4½ 8½	2 5	0 2	0 1	1 1	4 2½	7½ 5	11 7	PM		
	PM	13½ 9	14½ 9½	14 9	12 7	9 4½	6 2	3 0	1½ −½	1 ½	2 3	4 6	6 10	AM	22	23
23	AM	8 13	9 14½	8½ 14½	7 13	4½ 10	2 7	0 4	−½ 2	½ 1	2½ 2	6 3½	9 5	PM		
	PM	12½ 7	14 8	14½ 7½	13½ 6	11 4	8 2	5 0	3 −½	1½ 0	1½ 2	2½ 5	4 8½	AM	23	24
24	AM	6 11½	7 14	7 14½	6 14	4 12	2 9	0 6	−1 3½	−½ 2	1 1½	4 2	7 3½	PM		
	PM	10½ 5	13 5½	14½ 6	14 5	13 3½	10 1½	7½ 0	5 −1	3 1	2 ½	2 3	3 6	AM	24	25
25	AM	4 9½	5 12	5 14	4½ 14	3½ 13½	2 11	0 8½	−1 6	−1 4	0 2½	2 2	5 2½	PM		
	PM	8½ 3	11 4	13 4	14 3½	13½ 3	12 1½	10 0	7½ −1	5 1	3½ 0	2½ 1½	2½ 4	AM	25	26
26	AM	3 7½	3½ 10½	3½ 12½	3½ 14	2½ 13½	1½ 12½	½ 10	−½ [illegible]½	−1 6	½ 4	1 3	3 2½	PM		
	PM	6 2½	9 2½	11½ 3	13 2½	13½ 2	13 1	12 ½	10 −½	8 −1	6 −½	4 1	3 3	AM	26	27
27	AM	2½ 5	2 8	2 10½	2 12	2 13½	1½ 13½	1 12½	0 11	−½ 9	−½ 7	½ 5	2 3½	PM		
	PM	4 2½	6 2	9 1½	11 1½	12½ 1½	13½ 1	13½ 1	12½ ½	11 0	8½ 0	6½ ½	4½ 1½	AM	27	28
28	AM	3 3	2 5	1½ 7½	1½ 10	1½ 11½	1½ 13	1½ 13½	1 13	1 12	1 10	1 8	1½ 5½	PM		
	PM	2 3½	4 2	6 1	8 1	10 1	12 1½	13½ 1½	14 2	13 2	12 2	9½ 1½	7 1½	AM	28	29
29	AM	4½ 2	2½ 3	1 5	½ 7	½ 9	1½ 11½	2 13	2½ 14	3 14	3 12½	2½ 10½	2 8	PM		
	PM	2 5	2½ 3	3½ 1	5 ½	7½ ½	10 1	12½ 2	14 3	14½ 4	14 4	12½ 3½	10 3	AM	29	30
30	AM	7 2½	4 2	2 2½	½ 3½	0 6	1 8½	2 11	4 13½	5 14½	5½ 14½	5 13½	4½ 11	PM		
	PM	3 8	2 5	2 2	2½ ½	4 0	6½ 1	9½ 2½	12 4	14 6	15 7	14½ 7	12½ 6	AM	30	31
31	AM	9½ 4½	6½ 3	3 1½	1 1½	0 2½	½ 4½	2 8	4 11	6½ 13½	8 15	8½ 15	7½ 13½	PM		
	PM	6 11	4 7	2 3½	1 1	1 0	2½ 0	5½ 2	9 4½	12½ 7	14½ 9	15½ 10	14½ 9½	AM		

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Month: April 1958

		0 h		1 h.		2 h		3 h.		4 h		5 h.		6 h.		7 h.		8 h.		9 h		10 h.		11 h				
		12 h		13 h.		14 h		15 h.		16 h.		17 h.		18 h.		19 h.		20 h.		21 h		22 h		23 h				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W	Dates East of 180	Dates West of 180
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S			
Dates 1	AM	12	7½	8	5	4½	2	1½	½	0	0	0	1½	1½	4½	4½	7½	7½	11½	10	14	11½	15½	11	14½	PM		1
	PM	9½	12½	7	9	3½	5	1	2	−½	0	0	−½	2	1½	5½	4	9½	8	12½	10½	14½	12½	15	13	AM	1	2
2	AM	13½	11½	10½	8½	6½	5	3	2	0	−½	−½	−1	½	½	3	3½	7	7½	10½	11	13	13½	14½	14½	PM		
	PM	13½	13½	11	10½	7	7	3	3	0	0	−1½	−1	−1	0	1½	3	5	6½	9	10½	12	14	14	15½	AM	2	3
3	AM	13½	15	11½	13	8	9	4	5	1	1	−1	−1½	−½	−1½	1½	0	7½	3	9½	7	13½	10	16	12½	PM		
	PM	16½	13	15	11½	11½	8	7	4½	2½	1	−½	−1	−2	−1	−1½	1	1	4½	4½	9	8	13	11	16½	AM	3	4
4	AM	12	17½	11	16½	8½	13	5	8½	2	4	−½	0	−1½	−2	0	−2	3½	0	8	3	12½	6½	16	9½	PM		
	PM	18	11	18	10½	15	8	11	5	6	2	2	−½	−1	−1½	−2	−½	−1½	2½	2	7	4	12	7½	16	AM	4	5
5	AM	9½	18½	10	18½	8½	16½	6	13	2½	8	0	3	−1½	0	−1	−2	1	−2	5	0	10	2½	14½	5½	PM		
	PM	17½	8	19	8½	18	7½	15	5½	10½	2½	6	0	1½	−1½	−1	−1½	−2	½	−1	4	1	8½	3½	13½	AM	5	6
6	AM	6	17	7	19	7	18½	5½	16	3	12	½	7½	−1	3	−1½	0	0	−1½	2½	−1½	6½	0	11½	2	PM		
	PM	15½	4½	18	6	18½	6	17	5	14	3	9½	½	5½	−1	2	−1½	−½	½	−1½	2	−1	5½	1	10	AM	6	7
7	AM	3	14½	4½	17	5	18½	4½	17	3	14½	1	11	−1	6½	1½	3	−1	½	1	−1	4½	−½	8½	½	PM		
	PM	12½	2	15½	3	17½	4	17½	3½	16	2½	12½	1	9	−½	5	−1½	2	−1	0	1	−½	3½	0	7½	AM	7	8
8	AM	1	11	2	14½	3	16½	3	17	2½	16	1	13½	0	10	−1	6½	−1	3½	0	1	2	0	5½	−½	PM		
	PM	9	½	12	1	15	2	16	2	16	2	14	1	11½	½	8½	−½	5½	−½	3	0	1	2	0	5	AM	8	9
9	AM	0	7½	½	11	1	13	1½	15	1½	15	1	14	½	12½	0	9½	0	6½	½	4	1½	2	3½	½	PM		
	PM	6	0	9	0	11½	½	13½	1	14½	1	14	1	13	1	11	1	8½	½	5½	1	3½	2	1½	3½	AM	9	10
10	AM	½	5½	0	8	0	10½	½	12	1	13½	1	13½	1½	13	1½	11½	1½	9	2	7	2½	4½	3	2½	PM		
	PM	4½	1	6½	0	8½	0	10½	0	12	½	13	1	13	1½	12	2	10½	2½	8	2½	6	3	3½	3½	AM	10	11
11	AM	2	4½	½	5½	0	7	0	9	½	10½	1	12	2	12½	2½	12	3	11	3½	9	3½	7	4	4½	PM		
	PM	4	2½	5	1	6	0	7½	0	9	½	10½	1	12	2½	12	3	11½	4	10	4½	8½	4½	6	4	AM	11	12
12	AM	4	4	2	4½	½	5	0	6	0	7½	1	9	2½	11	4	11½	5	12	5½	11	5½	9	5	7	PM		
	PM	5	4½	4½	2½	4½	1	5½	0	6½	0	8	1	10	2½	11	4½	11½	5½	11	6½	10	6½	8	6	AM	12	13
13	AM	5½	5	3	4½	1½	4	½	4½	½	5½	1	7	3	9	4½	10½	6½	11½	7½	11½	8	10½	7½	8½	PM		
	PM	6	6	5	3½	4	1½	4	½	4½	½	6	1½	7½	3	9½	5½	11	7	11½	8½	11	9	9½	8½	AM	13	14

15	AM	8½ 9½	6 7½	3½ 5	1½ 3½	½ 2½	1 3	2½ 4½	5 6½	8 9	10 10½	12 11	12 10½	PM	14	15
	PM	11 9	9 6½	6 3½	4 1½	2½ ½	2 1	3 2½	5 5	7½ 8	9½ 11	11 13	11 13	AM	15	16
16	AM	9½ 12	7 9½	4 6½	2 4	½ 2	½ 1½	2 2½	4½ 4	8 7	11 9	13 10½	14 10½	PM		
	PM	13 9½	11 7	8 4	5 2	2½ ½	1½ 0	1½ 2	3 4½	5½ 8	8 11	9½ 13½	10½ 14½	AM	16	17
17	AM	9½ 14	7½ 12	5 9	2½ 5½	½ 3	0 1	1 1	3½ 2½	7 4½	10½ 7	13½ 9	15 10	PM		
	PM	15 9½	13 7½	10 5	6½ 2½	3½ ½	1 0	½ 1	1½ 3	3 6½	5½ 10	8 13½	9 15½	AM	17	18
18	AM	9 16	8 14	5½ 11	3 7½	1 4	0 1½	0 0	2 ½	5½ 2	9½ 4½	13 7	15½ 8	PM		
	PM	16 8½	15 7½	12½ 5½	8½ 3	5 ½	2 −½	0 0	0 2	1 5	3½ 9	5½ 13	7½ 15½	AM	18	19
19	AM	8 16½	7½ 15½	5½ 13	3 9	½ 5½	−½ 2	−½ 0	1 −½	4½ 1	8½ 2½	12 5	15 6½	PM		
	PM	16½ 7	16½ 6½	14 5	11 2½	6½ ½	3 −1	½ −1	−½ 1	0 4	1½ 8	3½ 12	5½ 15	AM	19	20
20	AM	6½ 17	6½ 16½	5 15	3 11½	½ 7½	1 3½	−1 1	0 −½	3 −½	6½ 1	10½ 2½	14 4½	PM		
	PM	16½ 5½	17 5½	16 4½	13 2½	9 ½	5 −1	2 −1½	0 −½	−½ 2	0 6	1½ 10	3 13½	AM	20	21
21	AM	4½ 16	5 17	4½ 16	3 13½	1 10	−1 6	−1½ 2½	−1 ½	1 ½	4 0	8 1	12 2½	PM		
	PM	15 3½	17 4	16½ 3½	15 2½	11½ ½	8 −1	4 −1½	1½ −1	0 ½	−½ 4	0 7½	1½ 11½	AM	21	22
22	AM	3 15	3½ 17	3½ 17	3½ 15	½ 12	−1 8½	−2 5	−1½ 2	0 0	2½ −½	6½ 0	10 1	PM		
	PM	14 2	16 3	16½ 3	16 2	13½ ½	10 −1	6½ 1½	3 −1½	1 ½	0 2	0 5½	½ 9½	AM	22	23
23	AM	1½ 13	2 15½	2½ 16½	2 16	1 14	−½ 11	−1½ 7½	−1½ 4½	−1 2	1 ½	4 0	7½ 0	PM		
	PM	11 1	14 1½	16 2	16 1½	15 1	12½ 0	9½ −1	6 −1½	3½ −1	1½ 1	½ 3½	0 6½	AM	23	24
24	AM	½ 10	1 13	1½ 15	1½ 16	1 15	½ 13	−½ 10½	−1 7½	−1 4½	½ 2	2½ 1	5 0	PM		
	PM	8 ½	11½ 1	13½ 1	15 1½	15 1	14 ½	12 0	9 0	6 0	3½ ½	1½ 2	½ 4½	AM	24	25
25	AM	½ 7½	½ 10½	1 13	1½ 14½	1½ 15	1 14	1 12½	½ 10	½ 7	1 4½	2 2½	4 1	PM		
	PM	6½ ½	9 ½	11½ ½	13 1	14 1½	14 2	13 2	11 1½	9 1½	6 1½	4 2	2 3½	AM	25	26
26	AM	½ 5½	0 7½	½ 10	1 12	1½ 13½	2½ 14	2½ 13½	2½ 12	2½ 10	2½ 7½	2½ 5	3 2½	PM		
	PM	4½ 1	6 ½	8 ½	10 1	12 2	13 3	13½ 3½	13 4	11 4	9 3½	6½ 3½	4 3½	AM	26	27
27	AM	2 4	½ 5	0 6½	½ 8½	1½ 10½	3 12	4 13	5 13	5½ 12	5 10	4½ 7½	4 5	PM		
	PM	4 2½	4 1	5 0	6½ ½	8½ 1½	10½ 3	12 5	13 6	12½ 7	11 7	9 6	6 5	AM	27	28
28	AM	3 4	1 3½	0 4	0 5	1 7	3 9	5 11	7 12	8 12½	8½ 11½	8 9	6½ 6½	PM		
	PM	5 3½	4 1½	3½ 0	3½ 0	5 1	7 3	9 5½	11 8	12 9½	12 10	10½ 9½	8 8	AM	28	29
29	AM	5 6	2½ 4	½ 3	0 2½	½ 3½	2½ 5	5 7½	8 10	10½ 11	11½ 11½	11½ 10½	10 8½	PM		
	PM	8 5½	5½ 2½	3 ½	2 −½	2 0	3 2	5 5	8 8½	10 11	11 13	11 13½	9½ 12	AM	29	30
30	AM	7 9½	4 6½	1 3½	−½ 1½	−½ 1	1 1½	4 3½	7½ 6	11 8½	14 10	15 10½	14 9½	PM		
	PM	12 7	9 4	5 1	2 −½	0 −1	0 ½	1½ 3½	4 7½	6½ 11½	9 15	10 16	9½ 16	AM	30	
31	AM													PM		
	PM													AM		

Table 2

Month May 1958

		0 h.		1 h		2 h		3 h		4 h		5 h.		6 h		7 h		8 h		9 h		10 h		11 h				
		12 h		13 h		14 h		15 h		16 h		17 h.		18 h		19 h		20 h		21 h		22 h		23 h				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	**165° W**	Dates	
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		East of 180	West of 180
Dates 1	AM	7½	13½	5	10	2	6	½	2½	-1½	0	½	-1	2½	0	6½	2	11	5	14½	7½	17	9	17½	9	PM		1
	PM	16	7½	12½	5	8	2	4	½	½	1½	1½	-1	-1½	1½	0	5½	3	10	5½	14½	7½	17½	8½	19	AM	1	2
2	AM	7½	17½	5½	14½	2½	10	0	5	-2	1	-2	1½	0	-2½	4	1	9	1	13½	4	17	6	19½	7½	PM		
	PM	19	7	16½	5½	12½	2½	7½	0	3	-2	-1	2	2½	-½	2½	2½	½	7½	2	12½	4½	16½	6	19½	AM	2	3
3	AM	6½	20	5½	18	3½	14	½	9½	-1½	4	2½	0	-1½	-2½	1	-3	5½	-2	10½	0	15½	3	19	5	PM		
	PM	20½	5½	19½	5	16½	3	11½	½	6½	-1½	1½	-3	1½	-2	-3	0	3	4	-1	9	1	14	3½	18½	AM	3	4
4	AM	4½	20½	4½	20	3	17	1	12½	-1	7½	2½	2½	-2½	-1	-1	3	3	3	8	2	13	0	17½	2	PM		
	PM	20	4	20½	4	18½	3	14½	1	10	-1	5	2½	½	3	2½	-1	-3½	2	-3	6½	1	11½	1	16	AM	4	5
5	AM	2½	19	3	20½	3	19	1½	16	-½	11	-2	6	-3	2	-2	1½	½	3	4½	3	9½	2	14	0	PM		
	PM	18	1½	19½	2½	19½	2½	17	1	13	½	8	-2	4	2½	0	2	-2	0	-3	3½	-2½	8	1	12	AM	5	6
6	AM	½	16	1½	18½	2	19	1½	17½	0	14	-1	10	2	5½	-2	1½	½	1½	2	2½	6	-2½	10½	2	PM		
	PM	14½	½	17	1	18½	1½	17½	1½	15	½	11½	-1	7	-1½	3	1½	0	-½	2	2	-2½	5	-2	9	AM	6	7
7	AM	1	13	½	16	1	17½	1½	17	1	15	0	12	1	8	1	4½	-½	1	1½	-1	4	2	7½	-2	PM		
	PM	11	1½	14	0	16	1	16½	1½	15½	1	13	½	9½	0	6	½	3	0	0	1½	-1	3½	2	6½	AM	7	8
8	AM	-1½	9½	-½	12½	½	14½	1	15½	1½	15	1	13	1	10½	½	7	1	4	1½	1½	3	0	5½	1½	PM		
	PM	8	-1½	11	-½	13	0	14½	1	14½	1½	13	2	11	2	8½	1½	5½	1½	3	2	½	3	½	5	AM	8	9
9	AM	-1	7	-1	9½	0	11½	1	13	2	13½	2½	13	2½	11½	2½	9	3	6½	3	4	3½	1½	5	0	PM		
	PM	6	1	8	-1	10	0	11½	1	12½	2	12½	2½	11½	3½	10	3½	7½	4	5	4	3	4	1	5	AM	9	10
10	AM	0	6	½	7½	0	9	1	10½	2	11	3	11½	4	11	4½	10	5	8	5	6	5	3½	5½	1½	PM		
	PM	6	0	6½	-½	8	0	9	1	10	2	11	3½	11	5	10	5½	8½	6	6½	6	4½	6	2½	6	AM	10	11
11	AM	1	6	0	6	0	7	2	8	2	9	3½	9½	5	10	6½	10	7	9	7½	7	7	5½	6½	3	PM		
	PM	6	1½	6	0	6	0	6½	½	7½	2	8½	4	9½	5½	9½	7	9	8	8	8½	6	8½	4	7½	AM	11	12
12	AM	2	6½	1	6	0	5½	½	6	1½	6½	3½	7½	5½	8½	7½	9	9	9	9½	8	9½	6½	8½	4½	PM		
	PM	7½	2½	6½	1	5½	0	5	0	5½	1½	6½	3½	7½	6	8	8	8½	10	8	11	7	11	5	9½	AM	12	13
13	AM	3	8	1½	6½	½	5½	0	4½	1	4½	3	5½	6	6½	8	7½	10½	8	11½	8	12	7	11	5½	PM		
	PM	9	3½	7	1½	5½	0	4	0	3½	1	4	3	5½	5½	6½	8½	7½	11	8	12½	7½	13	6	12	AM	13	14
	AM																											

15	AM	4½ 12½	2½ 10	1 7	½ 4	—½ 2½	1 1½	3½ 2	7 3	10½ 5	13 6	15 6½	15 6	PM	14	15
	PM	14 4½	11 3	8 1	5 ½	2½—1	1 0	1 3	2 6	4 10	5 13½	6 15½	6 16	AM	15	16
16	AM	5 14½	3 11½	1 8	½ 4½	—1 2	0 ½	2 ½	6 1½	10 3	13 4½	15½ 5½	16½ 5½	PM		
	PM	15½ 4½	13 2½	9½ ½	6 1	3 1½	½ —½	—½ 2	0 5½	1½ 9½	3 13	4½ 16	5 17	AM	16	17
17	AM	4½ 16½	3 14	1 10½	—1 6½	1½ 2½	—1½ 0	½—1	4 —½	8 ½	12 2½	15 3½	17 4½	PM		
	PM	17½ 4	15½ 2½	12 1	8 —1	4 2	1 —1½	—1 0	—1½ 3	—½ 7½	1 12	2½ 15	3½ 17½	AM	17	18
18	AM	4 18	3 16	1 13	½ 9	2 4½	—2 1	1 1	2 —2	6 —1	10 0	14 2	17 3	PM		
	PM	18 3	17 2½	14½ 1	10½ 1	6 —2	2 —2½	—½—1½	—2 1½	—2 5	—1 10	1 14	2 17	AM	18	19
19	AM	2½ 18½	2½ 17½	1 15	—1 11	2 6½	—3 2½	2 ½	½—2	4 2	8½—1½	13 0	16½ 1½	PM		
	PM	18 2	18 2	16 1	12½—1	8 —2	4 3	½ 2	—2 0	—2½ 3½	2 8	½ 12	½ 16	AM	19	20
20	AM	1½ 18	2 18½	1 17	—½ 13½	—2 9	—3 5	2½ 1	—1 -1½	2 2½	6 2	10½ 1	14½ 0	PM		
	PM	17½ 1	18½ 1½	17½ 1	15 —½	11 2	6½ -3	2½—3	—½—1½	2 1	2½ 5	—2 9½	½ 13½	AM	20	21
21	AM	½ 17	1 18½	1 18	0 16	—1 12	—2½ 8	—2½ 4	—2 ½	0 —1½	3½—2½	8 2	12 1	PM		
	PM	15½ 0	18 1	18 1	16½ 0	13½—1	9½ 2	5½—2½	2 —2	—1 0	2 3	—2 7	—1½ 11	AM	21	22
22	AM	0 15	½ 17½	1 18	½ 16½	0 14	—1½ 10	2 6	1½ 2½	-½ 0	2 -1½	5½—2	9½—1½	PM		
	PM	13½ —½	16 ½	17½ 1	17 1	15 0	12 —½	8 1½	4½—1½	1 —½	—1 2	—1½ 5	—1½ 8½	AM	22	23
23	AM	—1 12	0 15	1 17	1½ 17	1 15	½ 12½	0 9	—½ 5½	0 2	1 0	3½—1	6½—1½	PM		
	PM	10 —1	13 0	15 1	16 2	15½ 2	13½ 1½	10½ 1	7 ½	4 ½	1 1½	—½ 3	—1 6	AM	23	24
24	AM	—1½ 9	0 11½	1 14	2 15	2½ 15	2½ 14	2 11	1½ 8	1½ 5	2 2	3 0	4½—1	PM		
	PM	7 1	10 0	12 1	14 2	14½ 3	14 3½	12 3½	9½ 3	6½ 2½	3½ 2½	1 3	—½ 4½	AM	24	25
25	AM	—1 6	½ 8½	1 11	2 12½	3½ 13½	4½ 13	5 12	4½ 10	4 7	3½ 4	3½ 1½	4 0	PM		
	PM	5 —½	7 —½	9 ½	10½ 2	12 4	12½ 5	12 6	10½ 6	8 6	5½ 5	3 4½	½ 4½	AM	25	26
26	AM	—½ 5	-½ 6	0 7	2 9	3½ 10½	5½ 11	7 11	7½ 10½	7½ 8½	7 6	6 3½	5 1	PM		
	PM	4½ 0	5 —½	5½ 0	7 1½	8 3½	9½ 6	10 8	10 9	9 9½	7 9	4½ 7½	2 6	AM	26	27
27	AM	0 5	—½ 4½	½ 4½	1 5	3 6½	5½ 8	8 9	10 9½	11 8½	10½ 7	9½ 5	8 2½	PM		
	PM	6 ½	4½—1	3½—1	3½ 0	4½ 2½	6 5½	7 8½	8 11	8 12½	7 12½	5½ 11½	3 9½	AM	27	28
28	AM	1 7	—½ 5	-1 3	-½ 2½	1½ 3	4½ 4	8 5½	11 7	13 7½	14 7	13½ 5½	11½ 3½	PM		
	PM	9 1	6 ½	3½—1½	2 —1	1½ 1	2½ 4	4 8	5½ 11	6½ 14	6½ 15½	5½ 15½	4 13½	AM	28	29
29	AM	1½ 10½	0 7	—1½ 4	1½ 1½	0 ½	2½ 1	6½ 2	10½ 3½	14 5	16½ 6	17 5½	15½ 4	PM		
	PM	13 2	9 0	5 —2	2 2½	0 —1	—½ 1½	0 5½	1½ 10	3½ 14	4½ 17	5 18	4 17½	AM	29	30
30	AM	2½ 15	0 11	—1½ 7	2½ 3	-2 0	0 1½	4 1½	8½ 0	13 2	16½ 3½	18½ 4	19 4	PM		
	PM	17 2½	13 ½	8½—2	4 —3	½—3	—2 —1	2½ 2½	-1½ 7	0 12	2 16	3 19	3½ 20	AM	30	31
31	AM	2½ 18	½ 14½	-1½ 9½	3 5	—3½ 1	-2 2	1 —3	5½ 2½	10½—1	15½ 1	19 2½	20½ 3	PM		
	PM	19½ 2	16½ ½	12 -1½	7 —3	2 3½	-1½—2½	3½ 0	-3½ 4½	—2½ 10	—½ 15	1 18½	2 21	AM		

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		0 h.		1 h		2 h		3 h.		4 h.		5 h.		6 h		7 h		8 h.		9 h		10 h		11 h				
		12 h.		13 h.		14 h		15 h.		16 h.		17 h.		18 h.		19 h.		20 h		21 h		22 h		23 h				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W Dates		
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		East of 180	West of 180
Dates 1	AM	2	20½	1	18	−1	13½	2½	8½	4	3	−3½	−1	−1½	−3	2	−4	7	−3	12	−1½	17	0	20	1½	PM		1
	PM	21	2	19½	1	16	−1	11	−2½	5½	−4	1	−4	−2½	−2	−4	1	−4	6	3	11	−1	16	½	19½	AM	1	2
2	AM	1½	21	1	20	0	17	−2	12½	−3½	7	−4	2	−3	−2	−½	4	3½	−4½	8½	−3½	13½	−2	18	0	PM		
	PM	20	1	20½	1	18½	0	14	−1½	9	−3	4	3½	0	3	−3	−1	−4½	3	−4	7½	−2½	12½	−1	16½	AM	2	3
3	AM	½	20	1	20	½	18	−1	14½	−2½	9½	−3½	4½	−3	0	−1½	−3	1½	−4	6	−4	11	−3	15½	1	PM		
	PM	18½	½	19½	1	18½	½	15½	½	11	−1½	6½	−3	2	3	−1½	−1½	−3½	1	4	5	−3	9½	−1½	14	AM	3	4
4	AM	0	17	1	19	1	18½	½	16	−1	12	−2	7½	−2½	3	−1½	−½	0	−3	3½	−3½	7½	3	12	−2	PM		
	PM	15½	½	17½	1	18	1½	16½	1	13	0	9	−1	5	−1½	1	−1	−2	0	3	3	−3	6½	−2	10½	AM	4	5
5	AM	−1	14	½	16½	1½	17½	1½	16½	1	14	0	10	−½	6	−½	2	0	−1	2	−2½	5	−3	9	2	PM		
	PM	12	1	15	½	16	1½	16	2	14	2	11	1	7	½	3½	0	½	1	−1½	2½	−2½	4½	−2	7½	AM	5	6
6	AM	−1	11	½	13½	1½	15	2½	15	2½	14	2	11	1½	8	1	4½	1½	1½	2½	−1	4	−2	7	−2	PM		
	PM	9½	−1	12	½	14	2	14½	3	13½	3½	11½	3	9	3	5½	2½	2½	2½	½	3	−1	4½	1½	6	AM	6	7
7	AM	−1	8½	0	11	1½	12½	3½	13½	4	13	4	11½	4	9	3½	6	3½	3½	3½	1	4½	−½	5½	−1½	PM		
	PM	7½	−1	9½	0	11	1½	12	3	12½	4	11½	5	9½	5	7	5	4	4½	2	4½	0	5	−1	6	AM	7	8
8	AM	−1	7	0	8½	1	10	3	11	4½	11½	5½	10½	6	9½	6	7	6	5	5½	2½	5½	½	6	−½	PM		
	PM	6½	−1	7½	0	9	1	10	3	10½	4½	10	6	9	7	7½	7	5½	7	3	7	1½	6½	0	6½	AM	8	9
9	AM	−½	6½	0	7	1	8	2½	8½	4½	9	6	9	7½	8½	8	7½	8½	5½	8	3½	7½	1½	7	0	PM		
	PM	6½	−½	6½	−½	7	½	7½	2	8	4	8½	6	8	8	7½	9	6	9½	4	9	2½	8½	1	7½	AM	9	10
10	AM	0	7	−½	6½	0	6½	1½	6½	3½	7	6	7½	8	7½	9½	7	10½	6	10½	4½	9½	2½	8½	1	PM		
	PM	7½	0	6½	½	6	0	5½	1½	6	3	6	6	6½	8	6½	10	6	11	4½	11½	3	10½	1½	9½	AM	10	11
11	AM	0	8	−½	6½	−½	5½	½	5	2½	5	5	5	8	5½	10	5½	12	5½	12½	4½	12	3	10½	1½	PM		
	PM	9	0	7	−1	5½	−1	4	0	4	2	4	4½	4½	7½	5	10	5	12	4½	13	3½	13	2	11½	AM	11	12
12	AM	½	9½	−1	7	−1	5	−½	3½	1	3	4	3	7	3½	10	4	12½	4½	14	4	14	3½	13	2	PM		
	PM	10½	0	8	−1	5½	1½	3½	−1	2	½	2	3½	2½	6½	3	10	3½	12½	3½	14½	3	15	2	14	AM	12	13
13	AM	½	11½	−1	9	−1½	6	1½	3½	0	1½	2	1	5½	1½	9	2	12	2½	14½	3	15½	3	15	2	PM		
	PM	13	½	10	−1	7	−2	4	−2	1½	−1	½	1½	½	5	1	8½	2	12	2½	15	2½	16	2	16	AM	13	14

15	AM	1 16	−½ 13	−2 9	−3 5	−3 1½	−1 −1	1½ −2	5½ −2	10 −1	14 0	17 1	18 1½	PM		
	PM	17 1	15 −½	11 −2	7 −3	2½ −3½	−½ −2	−2 1	−2½ 5	−2 9	−½ 13½	½ 17	1 18½	AM	15	16
16	AM	1 18	0 16	−1½ 12	−3 7½	−3½ 3	−2½ 0	½ −2	3 −3	8 −2½	12 −1½	16 0	18½ 1	PM		
	PM	19 1	17 0	14 1½	9½ −3	5 −3½	1 −3	−2 −1	−3 2	−3 6½	−2 11	−½ 15½	½ 18½	AM	16	17
17	AM	1 19½	½ 18	−1 15	2½ 10½	−3½ 6	−3½ 1½	−2 −1½	½ −3	5 −3½	10 −2½	14 −1	18 0	PM		
	PM	19½ ½	19 ½	16½ −½	12½ −2	7½ −3½	3 −4	−½ −2½	−3 0	−3½ 4	−3 9	1½ 13	0 17	AM	17	18
18	AM	½ 19½	½ 19½	0 17	−1½ 13	−3 8½	−3½ 4	−3 0	−1 −2½	3 −3½	7 −3	12 −2	16 −½	PM		
	PM	19 ½	19½ 1	18 ½	15 −1	10½ −2	5½ −3	1½ −3	−1½ −1	−3 2	−3 6	−2 11	−1 15	AM	18	19
19	AM	½ 18	1 19½	1 18½	0 16	−1½ 12	2½ 7	−3 2½	−2 −1	½ −3	4½ −3	9 −2½	13 −1	PM		
	PM	17 ½	19 1½	19 1½	17 1	13 −½	9 −2	4 −2½	½ 2	−2 0	−3 3½	−2½ 7½	−1 12	AM	19	20
20	AM	½ 15½	1½ 18	2 18½	2 17	1 14	½ 10	−1½ 5½	−1½ 1½	0 1	2 −2½	6 2½	10 −1½	PM		
	PM	14 0	16½ 2	18 2½	17½ 2½	15 2	11 ½	7 ½	3 −1	0 0	−2 2	−2½ 5	−1½ 8½	AM	20	21
21	AM	0 13	2 15½	3 17	3½ 16½	3 14½	2 11½	1 7½	0 3½	½ ½	1½ −1½	4 2	7 −1	PM		
	PM	10½ 0	13½ 2	15½ 3½	16 4	15 4	12½ 3½	9 2½	5 1½	2 1	−½ 2	−1½ 3½	−1½ 6½	AM	21	22
22	AM	0 9	1½ 12	3½ 14	4½ 15	5 14	5 12	4 9	3 5½	2½ 2½	2½ 0	3 −1	5 1½	PM		
	PM	7½ −½	10 1½	12 3½	13½ 5	13½ 6	12½ 6	10 5½	7 4½	3½ 4	1 3½	−1 3½	−1½ 4½	AM	22	23
23	AM	−1 6½	1 8	3 10½	5 12	6½ 12½	7 11½	7 9½	6½ 7	5½ 4	4½ 1½	4 ½	4½ −1	PM		
	PM	5 −1	6½ ½	8 2½	10 5	10½ 7	10½ 8	9½ 8½	7½ 8½	5 7½	2½ 6	0 5	−1 4½	AM	23	24
24	AM	−1 5	0 5½	2 7	4½ 8	6½ 9	8½ 9	10 8½	10 7	9 4½	8 2½	6½ ½	5½ −1	PM		
	PM	5 1	5 −½	5½ 1½	6 4	7 6½	7½ 9	7½ 11	6½ 11½	5 11	3 10	1 8	−½ 6½	AM	24	25
25	AM	−1½ 5	−1 4½	0 4	3 4½	5½ 5½	8½ 6	11 6½	12½ 6	12½ 4½	12 3	10½ 1	8 −½	PM		
	PM	6 −1½	4½ −1½	3½ −½	3 2	3½ 5	4 8	5 11	5 13	4½ 14	3 13½	1½ 12	0 10	AM	25	26
26	AM	−1½ 7	−2 5	−1½ 3	½ 2	3 2	7 2½	10 3	13 3½	15 3½	15 3	14 1½	12 0	PM		
	PM	9 −1½	6 2½	3½ −2	1½ −½	1 2	1 6	1½ 10	2½ 13	3 15½	2½ 16½	1½ 16	½ 13½	AM	26	27
27	AM	−1½ 10½	−2½ 7	−2½ 3½	−1½ 1	1 0	4½ −½	8½ 0	12 1	15½ 2	17 2	17 1½	15½ 0	PM		
	PM	12½ −1	8½ −2½	5 −3	1½ −2½	−½ 0	−1½ 3	−1 7½	−½ 11½	½ 15½	1 18	1 18½	½ 17	AM	27	28
28	AM	−1 14	−2 10	−3 6	−3 2	−1½ ½	1 −2	5½ −2	10 1½	14 −½	17½ ½	19 1	18½ ½	PM		
	PM	16 −½	12½ −2	8 −3½	3½ −3½	0 −2½	−2½ 0	−3 4	−2½ 8½	−1½ 13	0 17	½ 19	½ 19½	AM	28	29
29	AM	0 17½	−1½ 14	−3 9½	−4 5	−3½ ½	1½ −2	2 −3½	6½ −3½	11½ 2½	15½ −1	18½ 0	20 ½	PM		
	PM	19 0	16 −1	11½ −3	6½ −4	2 −4	−2 2½	−3½ 1	−4 5	−3 10	−2 15	−½ 18	½ 20	AM	29	30
30	AM	½ 19½	−½ 16½	−2 12	−3½ 7	−4 2½	−3 −1½	−½ 3½	3 −4	8 −3½	13 −2	17 −½	19½ ½	PM		
	PM	20 ½	18 0	14 −2	9½ −3	4½ −4	0 −3½	−3 −1	−4 2½	−4 7	−3 12	−1 16½	½ 19½	AM	30	
31	AM													PM		
	PM													AM		

Table 2

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		0 h		1 h		2 h		3 h		4 h		5 h		6 h		7 h		8 h		9 h		10 h		11 h		165° W		
		12 h		13 h		14 h		15 h		16 h		17 h		18 h		19 h		20 h		21 h		22 h		23 h		Dates		
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N		East of 180	West of 180
15° E Dates		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S			
1	AM	1	20	1/2	18 1/2	1/2	15	-2	10	3 1/2	5	-3 1/2	1	2 1/2	-2 1/2	1/2	-4	5	-4	9 1/2	-3	14 1/2	1	18	1/2	PM		1
	PM	19 1/2	1	19	1	16 1/2	0	12 1/2	1 1/2	7 1/2	3	2 1/2	-3 1/2	-1	-2 1/2	-3 1/2	0	4	4	3 1/2	8 1/2	1 1/2	13	0	17	AM	1	2
2	AM	1 1/2	19	-2	19	1	17	0	13	-2	8 1/2	3	3 1/2	2 1/2	1/2	-1	-3	2	4	6	3	11	-1 1/2	15	0	PM		
	PM	18	1 1/2	19	2 1/2	17 1/2	2	14 1/2	1/2	10	1	5 1/2	2	1	2	-2	-1	-3 1/2	2	3	5 1/2	-2	10	0	14	AM	2	3
3	AM	2	17	2 1/2	18	2 1/2	17	1 1/2	14 1/2	0	10 1/2	1	6	-1 1/2	2	-1	-1	1	-3	4 1/2	3	9	2	13	0	PM		
	PM	16	2	17 1/2	3	17	3 1/2	15	2 1/2	11	1 1/2	7	0	3	1	0	1/2	2	1	-2 1/2	4	2	7 1/2	0	11	AM	3	4
4	AM	2	14 1/2	3	16 1/2	4	16 1/2	3 1/2	15	2 1/2	12	1	8	1/2	4	0	1/2	1	-1 1/2	3	-2 1/2	6	1 1/2	10	0	PM		
	PM	13	2	15	3 1/2	16	4 1/2	15	4 1/2	12	4	8 1/2	2 1/2	5	1 1/2	1 1/2	1	1	1 1/2	-2	3	1 1/2	5 1/2	0	8 1/2	AM	4	5
5	AM	1 1/2	11 1/2	3 1/2	14	5	15	5 1/2	14 1/2	5	12 1/2	4	9 1/2	2 1/2	5 1/2	2	2 1/2	2	0	3	1 1/2	5	1 1/2	8	1/2	PM		
	PM	10 1/2	1 1/2	12 1/2	3	14	5	14	5 1/2	12	5 1/2	9 1/2	5	6	4	3	3	1/2	3	1	3 1/2	1 1/2	5	1/2	7	AM	5	6
6	AM	1	9 1/2	3	11 1/2	5	13	6	13	6 1/2	11 1/2	6	9	5	6	4 1/2	3 1/2	4	1/2	4	1/2	5	-1	6 1/2	1/2	PM		
	PM	8 1/2	1	10	3	11 1/2	5	12	6 1/2	11 1/2	7	9 1/2	7	7	6	4	5 1/2	1 1/2	5	0	4 1/2	-1	5	1/2	6 1/2	AM	6	7
7	AM	1/2	8	2 1/2	9 1/2	4 1/2	10 1/2	6	11	7	10 1/2	7 1/2	9	7 1/2	6 1/2	6 1/2	4	6	2	5 1/2	0	5 1/2	1/2	6	1/2	PM		
	PM	7	1/2	8	2	9 1/2	4	10	6	10	7 1/2	9	8	7	8	5	7 1/2	2 1/2	7	1/2	6 1/2	1/2	6	1/2	6	AM	7	8
8	AM	0	6 1/2	1 1/2	7 1/2	3	8	5 1/2	9	7	8 1/2	8 1/2	8	9	6 1/2	9	4 1/2	8	2 1/2	7 1/2	1	7	1/2	6 1/2	1	PM		
	PM	6 1/2	-1/2	7	1	7	3	7 1/2	5	8	7	7 1/2	8 1/2	6 1/2	9 1/2	5	10	3	9 1/2	1	8 1/2	0	7 1/2	1/2	7	AM	8	9
9	AM	1/2	6 1/2	1/2	6	2	6 1/2	4	6 1/2	6 1/2	6 1/2	8 1/2	6	10	5 1/2	10 1/2	4	10 1/2	2 1/2	9 1/2	1	8 1/2	0	7 1/2	1	PM		
	PM	6 1/2	-1	6	0	5 1/2	1 1/2	5 1/2	4	5 1/2	6	5 1/2	8 1/2	5	10	4	11	3	11	1 1/2	10 1/2	0	9 1/2	1/2	8	AM	9	10
10	AM	-1	7	1/2	5 1/2	1/2	5	2 1/2	4 1/2	5	4 1/2	7 1/2	4	9 1/2	4	11	3 1/2	12	2 1/2	12	1 1/2	11	0	9 1/2	1	PM		
	PM	7 1/2	1 1/2	6	-1	4 1/2	0	4	2	3 1/2	4 1/2	3	7	3	10	3	11 1/2	2 1/2	12 1/2	1 1/2	12 1/2	1/2	12	1/2	10	AM	10	11
11	AM	-1	8	1 1/2	6	-1	4	1	3	3	2 1/2	6	2	9	2	11	2	13	2	13 1/2	1 1/2	13	1/2	11 1/2	-1/2	PM		
	PM	9 1/2	1 1/2	7	-2	4 1/2	1 1/2	3	0	1 1/2	2 1/2	1	5 1/2	1	8 1/2	1 1/2	11 1/2	1 1/2	13 1/2	1	14 1/2	1/2	14	0	12	AM	11	12
12	AM	1	10	-2	7	2	4 1/2	-1	2	1	1	4	1/2	7 1/2	1/2	10 1/2	1/2	13 1/2	1	15	1	15	1/2	14	0	PM		
	PM	11 1/2	1 1/2	8 1/2	-2	5 1/2	2 1/2	2 1/2	1 1/2	1/2	1/2	1/2	3 1/2	-1/2	7	0	10 1/2	1/2	13 1/2	1	15 1/2	1/2	16	0	15	AM	12	13
13	AM	-1	12 1/2	2	9	2 1/2	5 1/2	2	2 1/2	1	0	1 1/2	1	5	1 1/2	9	1	13	0	15 1/2	1/2	17	1/2	16 1/2	0	PM		
	PM	14 1/2	-1	11	-2	7	-3	3 1/2	3	1	1 1/2	1	1	2	4 1/2	1 1/2	8 1/2	-1	12 1/2	0	15 1/2	1/2	17 1/2	1/2	17 1/2	AM	13	14
	AM	-1/2	15 1/2	-1 1/2	12																							

15	PM	19	1	16½	0	12½	1½	8	-3	3½	-3½	0	2½	-2½	0	3	3½	-2½	8½	-1	13	½	17	1½	19½	AM	15	16
16	AM	1½	19½	1	17½	½	14	-2½	9	3½	4½	-3	0	-1½	2½	2	-3	6½	-2½	11½	-1½	16	½	19	2	PM		
	PM	20	2	19	1½	16	0	11	-2	6	3	2	-3½	1½	-2	-3	1	-3	5	2	10	0	14½	2	18	AM	16	17
17	AM	3	20	2½	19½	1½	17	-½	12½	-2	7½	-3	3	-2½	-1	-½	-2½	3	-3	8	-2	13	0	17	2	PM		
	PM	19½	3	20	3½	18	2½	14	½	9½	1½	4½	-2½	½	2½	-2	-1	-3	2½	2	7	0	11½	2	16	AM	17	18
18	AM	3½	19	4	19½	3½	18	2	14½	0	10	-2	5	-2½	1	-1½	-1½	1½	2½	5½	-2	10	0	14½	2	PM		
	PM	17½	4	19	5	18	4½	15½	3	11½	1	6½	-½	2	-1½	-1	1½	-2	½	-2	4	-½	8½	2	12½	AM	18	19
19	AM	4	16	5½	18	6	18	5	16	3	12	1	7½	-½	3	1	0	0	2	3	-2	6½	-½	10½	1½	PM		
	PM	14½	4	16½	6	17	6½	16	6	13	4½	9	2½	4½	½	1	0	-1	0	-1½	2	-1	5	1	9	AM	19	20
20	AM	4	12	6	15	7	16	7½	15½	6	13	4½	9½	2½	5½	1	2	½	-1	1½	-1½	4	-1	7	1	PM		
	PM	10½	3	13	6	14½	7½	14½	8	13	7½	10	6	6	4	2½	2½	0	1½	-1½	2	-1	3	½	6	AM	20	21
21	AM	3	9	5½	11½	7½	13	9	13	9	12	8	9	6	6	4½	3	3	0	2½	1	3	1	4½	0	PM		
	PM	7	2½	9	6	11	7½	11½	9	11	9½	9½	9	7	7½	4	6	1	4½	-½	3½	-1	3½	-½	4	AM	21	22
22	AM	1½	6	4	7½	6½	9	9	10	10	9½	10½	8	9½	6	8	3½	6½	1	5	-½	4	1½	4	-½	PM		
	PM	4½	1	6	3½	7	6	8	9	8½	10½	8	11	6	11	4	10	2	8	0	6½	-1	5	-1	4½	AM	22	23
23	AM	0	4½	2	5	5	5½	7½	6½	10	7	11½	6½	12	5	11½	3½	10	2	8½	0	7	-1	5	1½	PM		
	PM	4½	-½	4	1	4	4	4½	7	5	9½	5	11½	4½	13	3½	13	2	12	½	10	-1	8	1½	6	AM	23	24
24	AM	-1	4½	0	3½	2½	3	5½	3	8	3½	11	3½	13	3	13½	2½	13½	1½	12	½	10	-1	8	1½	PM		
	PM	5½	1½	4	-½	2½	1½	2	4	2	7½	2	10½	2½	13	2	14	1½	14½	½	13½	-½	12	1½	9	AM	24	25
25	AM	-1½	6½	-1	4	0	2	2½	1	5½	½	9	1	12	1	14	1	15½	1	15	½	14	-½	11½	1	PM		
	PM	8	-2	5	-2	2½	-1	1	1	0	4	½	8	0	11½	½	14	½	16	½	16½	0	15	-1	13	AM	25	26
26	AM	-1½	9½	-2	6½	-2½	3	0	½	2½	-1	6	-1½	9½	1	13	-½	15½	0	17	½	16½	0	14½	½	PM		
	PM	12	-1½	8	-2	4	2	1	-1	-1	1	-2	4½	-2	8	1½	12	½	15½	0	17	0	17½	0	16	AM	26	27
27	AM	-1	13	-2	9	2½	5	-2	1½	0	1	2½	2½	6½	-2½	10½	-2	14½	½	17	0	18	½	17	0	PM		
	PM	15	-½	11	1½	7	-2½	3	-2½	0	-1	-2½	1½	-3	5	2½	9½	1	13½	0	16½	½	18	1	18	AM	27	28
28	AM	0	16	1	12½	-2	8	-2½	4	-2	0	0	2	3	-3	7	-2½	11½	-1½	15½	0	18	1	18½	1½	PM		
	PM	17	1	14	-½	10	2	5	-2½	1½	2½	2	-1	3	2	-3	6	2	10½	0	14½	1	17½	2	19	AM	28	29
29	AM	1½	18	½	15½	-1	11	-2	6½	2½	2	-2	-1	½	-3	4	3	8½	-2	13	0	16½	1½	18½	2½	PM		
	PM	18½	2½	16½	1½	13	0	8	-1½	3½	-2½	0	-2	2½	0	3	3	2	7	½	12	1½	15½	3	18	AM	29	30
30	AM	3½	18½	2½	16½	1	13	½	9	-2	4½	-2	½	-1	-2	2	2½	6	-2	10½	0	14½	2	17½	3½	PM		
	PM	18½	4	17	3½	14	2	10	½	5½	-1½	1½	2	1	1	-2½	1	2	5	-½	9	2	13	3½	16½	AM	30	31
31	AM	5	18	5	17½	3½	15	1½	11	0	6	1½	2	1½	-½	0	2	3½	-1½	7½	0	11½	2	15	4	PM		
	PM	17	5½	17½	6	15½	4½	12	3	8	1	3½	-1	0	-1	-1½	0	1½	3	-½	6½	2	10½	4	14	AM		

Table 2

Month: August 1958

		0 h		1 h.		2 h.		3 h.		4 h.		5 h.		6 h.		7 h.		8 h.		9 h		10 h		11 h				
		12 h.		13 h.		14 h		15 h.		16 h.		17 h		18 h.		19 h.		20 h.		21 h.		22 h		23 h.				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W	Dates	
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		East of 180°	West of 180°
Dates 1	AM	6	16½	6½	17	6	15	4	12	2	8	½	4	−½	½	0	−1	2	−1½	5	0	9	2	13	4½	PM		1
	PM	15½	6½	16½	7	15½	6½	13	5½	9	3½	5	1½	1½	0	−½	½	1	2	½	5	1½	8½	4	12	AM	1	2
2	AM	6	14½	7½	15½	8	15	6½	13	5	9	3	5½	1½	2	1	0	1½	−1	4	0	7	1½	10	4	PM		
	PM	13	6½	14½	8	14½	8½	13	7½	10	6	6½	4	3	2	½	1½	−1	2	½	4	1	6½	3½	9½	AM	2	3
3	AM	6	12	7½	13½	9	14	8½	12½	7	10	5½	6½	3½	3	2½	½	2	−½	3	−½	5½	1	8	3½	PM		
	PM	10½	5½	12½	8	13	9	12	9	10	8	7	6½	4	4½	1½	3	0	2½	−½	3½	½	5	2½	7½	AM	3	4
4	AM	5½	10	7½	11½	9	12	9½	11½	8½	9½	7	7	5½	4	4	1½	3½	0	3½	−½	5	½	6½	2½	PM		
	PM	8½	5	10	7	11	9	10½	9½	9	9½	7	8	4	7	1½	5½	0	4½	−½	4	0	5	2	6	AM	4	5
5	AM	4	7½	6½	9	8½	10	9½	10	10	8½	9	6½	8	4½	6½	2	5	½	4½	−½	5	0	5½	1½	PM		
	PM	7	3½	8	5½	9	8	9	9½	8	10	6½	9½	4	9	2	7½	½	6	−½	5½	−½	5	1	5½	AM	5	6
6	AM	2½	6	5	7	7	7½	9	8	10	7	10	6	9½	4	8½	2	7	½	6	−½	5½	−½	5½	½	PM		
	PM	5½	2	6	4	6½	6	7	8	6½	9½	5½	10	4	10	2½	9½	½	8½	0	7	½	6	0	5½	AM	6	7
7	AM	1	5½	3	5½	5½	5½	7½	5½	9	5½	10½	4½	11	3½	10½	2	9½	1	8	0	7	−½	6	½	PM		
	PM	5½	½	5	2½	5	4½	4½	7	4½	9	4	10	3	11	2	11	1	10½	0	9½	−½	8	−½	6½	AM	7	8
8	AM	0	5½	1½	4½	3½	4	5½	3½	8	3½	10	3	11	2½	11½	2	11½	1	10½	0	9	½	7½	−1	PM		
	PM	6	−½	4½	1½	3½	2½	3	5	2½	7	2	9½	2	11	1½	12	1	12½	0	12	−½	10½	−1	8½	AM	8	9
9	AM	−½	6½	0	5	1½	3	3½	2	6	1½	8½	1½	11	1½	12½	1	13	1	13	½	12	0	10	−1	PM		
	PM	7½	−1	5½	−½	3	½	2	2½	1	5	½	8	½	10½	1	12½	1	14	½	14	0	13	−½	11	AM	9	10
10	AM	−1	8½	−1	6	0	3½	1	1½	3½	½	6½	0	9½	0	12	½	14	1	15	1	14½	½	12½	0	PM		
	PM	10	−1	7	−1	4	−1	1½	0	0	2½	−½	5½	−½	9	0	12	½	14½	1	15½	1	15½	½	14	AM	10	11
11	AM	−½	11½	−1	8	−1½	5	−½	2	1	0	4	1	7½	1	11	0	14	½	16	1½	16½	1½	15½	1	PM		
	PM	13	0	9½	−1	6	−1½	2½	−1½	0	0	1	2½	1½	6	−½	10	½	13½	1½	16	2	17½	1½	17	AM	11	12
12	AM	1	14½	−½	11	−1½	7	−2	3	−1	½	1	−1½	4½	1½	9	−1	13	½	16	1½	18	2½	18	2½	PM		
	PM	16	1½	13	0	8½	−1	4	−2	1	−1½	−1	0	−2	3	−1	7	0	11½	2	15½	3	18	3½	18½	AM	12	13
13	AM	3	17	1	13½	−½	9	−2	4½	−2	1	−1	−1½	2	2	5½	−1	10½	½	15	2½	18	4	19	4½	PM		
	PM	18	3½	15½	2	11½	0	7	−1½	2½	−2½	−½	−1½	−2	1	−1½	5	0	9½	2	14	4	18	5	19½	AM		

15	PM	18½	8	18½	8	16	6	12	3	7½	½	3	−1½	0	−2	−1½	−½	−1	3	1	7	4	11½	7	15½	AM	15	16
16	AM	9	18	9	18	8	16	5	12	2	7½	−½	3	−1½	0	−1	−1½	1	−1	5	1½	9½	4½	13½	7½	PM		
	PM	16½	9½	17½	10	16	9	13	6½	9	3½	4½	½	1	−1	−1	−1	−1	½	½	4	3½	8	7	12	AM	16	17
17	AM	9½	15	11	16½	10½	15½	9	13	6	9	3	5	½	1	−½	−1	0	−1	2	½	5½	3½	9½	7	PM		
	PM	13	9½	15	11½	15	11½	13	10	10	7½	6	4	2½	1½	0	0	−1	0	0	1½	2	4½	5½	8	AM	17	18
18	AM	9	11	11	13	12	13½	11½	12½	9½	9½	7	6	4	2½	1½	0	½	−1	1	0	3	2	6	5	PM		
	PM	9	8½	11	11	12	12½	11½	12½	9½	11	6½	8	3½	5½	1	3	−1	1½	−1	1½	½	2½	3½	4½	AM	18	19
19	AM	7	7	10	9½	12½	10½	13	10	12½	8½	10	6	7½	3	5	1	3	−½	2	−1	2	½	3½	3	PM		
	PM	5½	6½	7	9½	8½	12	9	13	8	13	6	11½	3½	9	1	6½	−½	4½	−1	3	0	2½	2	3	AM	19	20
20	AM	5	4	8	5½	11	7	13	7	13½	6½	13	5	11	3½	9	1½	6½	0	4½	−1	3	−½	3	1	PM		
	PM	3½	4	4	7	5	10	5½	12	5½	13½	4½	13½	3	12½	1½	10½	0	8	−1	6	−1	4	½	3	AM	20	21
21	AM	3½	3	5	3	8	3½	11	4	13	4	13½	3½	13½	2½	12	1½	10	0	8	−½	6	−1	4	0	PM		
	PM	3	1½	2½	4	2½	7	3	10	3	12	2½	13½	2	14	1½	13	½	11½	−½	9½	−½	7½	−½	5	AM	21	22
22	AM	1	3½	3	2½	5½	2	8	1½	11	1½	13	1½	14	1½	14	1	13	½	11½	0	9	−½	6½	−½	PM		
	PM	4	½	2½	2	1½	4	1	7	½	9½	½	12	1	14	1	14½	½	14	0	13	0	11	−½	8	AM	22	23
23	AM	0	5½	1	3	2½	1	5	0	8	0	10½	0	13	0	14½	½	15	1	14	½	12½	0	10	0	PM		
	PM	7	0	4	½	1½	1½	0	3½	−1	6	−1	9	−½	12	0	14	½	15	1	15	½	14	½	11½	AM	23	24
24	AM	0	8	0	5	½	2	2	0	4½	−1	7	−1½	10½	−1	13	0	15	1	16	1½	15	1½	13	1	PM		
	PM	10	½	6½	0	3	0	½	1	−1	3	−1½	6	−1	9	0	12	1	15	2	16	2	16	2	14	AM	24	25
25	AM	1	11	½	7½	0	4	½	1	1½	−1	4	−2	7½	−1½	11	0	14	1	16	2½	16½	3	15	2½	PM		
	PM	12½	2	9	½	5	0	2	0	−½	1	−1½	3	−1½	6	−½	10	1	13	3	16	3½	16½	3½	16	AM	25	26
26	AM	3	13½	1½	10	½	6	−½	2½	0	0	1½	−1½	4½	−1½	8	0	12	1½	15	3½	16½	4½	16½	5	PM		
	PM	15	4	11½	2½	8	1	4	0	1	−½	−1	1	−1	3½	−½	7	1½	11	3½	14	5	16	5½	17	AM	26	27
27	AM	5	15½	4	12½	2	8½	½	5	−½	1½	0	−½	2	−1	5	0	9	2	13	4	15½	6	16½	6½	PM		
	PM	16	6½	13½	5	10	3	6	1	2½	−½	0	−½	−1	1½	−½	4	1½	8	4	12	6	15	7½	16½	AM	27	28
28	AM	7½	16	6	14	4	10½	2	6½	0	3	−½	0	½	−½	3	0	6½	2	10½	4	14	7	16	8½	PM		
	PM	16	8½	14½	7½	11½	5	7½	3	4	½	1	−½	−½	0	0	2½	1½	5½	4	9	7	13	9	15	AM	28	29
29	AM	9½	16	8½	14½	7½	12	4	8	2	4	0	1	0	0	1½	0	4	1½	8	4	11½	7	14	9	PM		
	PM	15½	10½	15	9	12½	8	9	5	5	2½	2	½	0	0	0	1	1	3½	4	7	7	10½	9	13	AM	29	30
30	AM	11	15	11	14½	9½	12½	7	9	4	5½	1½	2½	½	½	1	0	3	1	5½	3½	9	6½	12	9½	PM		
	PM	14	11	14	11½	12½	10	9½	8	6	5	3	2½	½	1	0	1	1	2½	3	5	6	8½	9	11	AM	30	31
31	AM	11	13	12	13½	11	12	9	9½	6	6½	3½	3	1½	1	1	0	2	1	4	3	7	6	10	9	PM		
	PM	12	11½	13	12½	12	12	10	10	6½	7	3½	4½	1	2½	0	1½	½	2	2	4	5	6	8	9	AM		

Table 2

Month: September 1958

		0 h.		1 h.		2 h.		3 h		4 h.		5 h		6 h.		7 h		8 h		9 h		10 h		11 h				
		12 h.		13 h		14 h		15 h		16 h		17 h.		18 h		19 h		20 h		21 h		22 h		23 h				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165 W Dates		
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		East of 180	West of 180
Dates 1	AM	11	11	12	12	12½	11½	11	9½	8½	6½	6	3½	3½	1	2	0	2	0	3	2	5	4½	7½	7½	PM		1
	PM	10	10½	11	12	11	12½	9½	11½	7	9½	4	6½	1½	4½	0	2½	0	2	1	3	3½	4½	7	7	AM	1	2
2	AM	9½	8½	12	9	12½	9	12	8½	10½	6½	8	4	5½	1½	3½	0	2½	0	3	1	4	3	6	6	PM		
	PM	7½	9	8½	11	9	12½	8	12½	6	11	4	9	2	6½	0	4½	−½	3	½	3	2	4	5	5	AM	2	3
3	AM	8	6½	10½	8	12	8	12½	7	11½	6	9½	3½	7½	2	5½	0	4	−½	3½	0	3½	2	4½	4½	PM		
	PM	5½	7½	6½	10	7	11½	6½	12	5½	11½	3½	10	2	8½	0	6½	½	5	0	4	1½	3½	3½	4	AM	3	4
4	AM	6	5	9	5½	11	6	12	5½	12	4½	11	3	9½	2	7½	½	6	−½	4½	0	4	1	4	3	PM		
	PM	4½	5½	5	8	5	10	5	11½	4	12	3	11½	1½	10	½	8½	−½	7	−½	5½	½	4½	2	4	AM	4	5
5	AM	4	4	6½	4	9	4	11	4	11½	3½	12	2½	11	1½	10	½	8	0	6½	½	5	0	4	1½	PM		
	PM	4	3½	3½	6	3½	8	3	10	3	11	2	12	1½	11½	½	11	0	9½	½	7½	0	6	1	5	AM	5	6
6	AM	2½	4	5	3	7	3	9	2½	10½	2	12	2	12	1½	11½	1	10½	½	9	0	7	0	5½	1	PM		
	PM	4	2	3	4	2	6	2	8	1½	10	1½	11½	1	12½	1	12½	½	12	0	10½	0	8½	½	6½	AM	6	7
7	AM	1½	4½	3	3	4½	2	7	1½	9	1	11	1	12½	1	13	1	13	1	12	1	10	½	7½	½	PM		
	PM	5½	1	3½	2	2	3½	1	5½	½	8	½	10	1	12	1	13½	1½	14	1½	13	1	11½	1	9	AM	7	8
8	AM	1	6½	1½	4	2½	2	4	1	6½	0	9	½	11½	1	13½	1½	14½	2	14	2	13	2	10½	1½	PM		
	PM	8	1	5	1	2½	1½	½	2½	0	5	0	7½	½	10½	1½	13	2½	14½	3	15	2½	14½	2	12½	AM	8	9
9	AM	1½	9	1	6	1	3	2	1	3½	0	6½	0	9½	½	12½	2	15	3	16	4	15½	4	13½	3½	PM		
	PM	10½	2	7	1	3½	½	1	1	−½	2	−½	5	½	8	2	11½	3½	14½	4½	16	5	16½	4½	15	AM	9	10
10	AM	3	12	1½	9	½	5	0	2	1	0	3½	½	6½	0	10	2	14	4	16	5½	17	6	16	6	PM		
	PM	13½	4½	10	3	6	1	2	0	0	0	−1	2	0	5	2	8½	4	12½	6	15½	7½	17	7	17	AM	10	11
11	AM	6	15	4	11½	1½	7½	0	3½	½	½	½	½	3	0	7	1½	11	4	14½	6½	17	8½	17½	9	PM		
	PM	15½	8	12½	5½	8	3	4½	0	1	−1	1	−1	−½	1½	1	5	5	9	7½	13	9½	16	10	17½	AM	11	12
12	AM	9	16½	7	13½	4	9½	1	5	−1	1½	−1	½	0	½	3½	1	8	4	12	7	15½	9	17	11	PM		
	PM	16½	11	14	9	10	6	6	2½	2	½	0	1½	−1	−1	½	1½	4	5½	7	10	10	14	12	16	AM	12	13
13	AM	12	16½	10½	15	7½	11½	3½	7	½	3	1½	0	−1½	−1	½	0	4	3	8	6½	12	10	15	13	PM		
	PM	16	13½	14	12½	11½	10	7½	6	3	2	½	−1	1	−2	0	−1	2	2	6	5½	10	10	13	13	AM		
	AM	14½	15	14																								

15	AM	15 12	16 12½	14½ 11½	11½ 8½	7½ 5½	3½ 2	½ −½	−1 −1	−1 0	1 3½	[illegible]	[illegible]			
	PM	10 15	11 16½	11 16	8½ 13½	5½ 9½	2 5½	0 2	−1 0	0 −1	2½ 0	6 2½	10½ 5½	AM	15	16
16	AM	14 8	16 10	16½ 9½	15 8	11½ 5½	7½ 2½	4 0	1 −1	0 −½	0 1½	1½ 5	4 9	PM		
	PM	6½ 13	8 15½	8½ 16½	7½ 15	5 13	2½ 9½	½ 6	−1 2½	−1 ½	½ 0	3½ 1	7½ 2½	AM	16	17
17	AM	11½ 4½	14½ 6	16 7	16 6½	14½ 5	11½ 3	8 ½	4½ −1	2 −1	½ 0	½ 2½	1½ 6	PM		
	PM	3 10	4½ 13	5½ 15½	5½ 16	4 15	2½ 13	1 10	½ 6½	−1 3½	0 2	1½ 1	5 1	AM	17	18
18	AM	8½ 2	12 3	14½ 4	15½ 4	15½ 3½	14 2½	11½ 1	8½ 0	5½ −1	3 −½	1½ 1	1 3½	PM		
	PM	1½ 7	2 10	2½ 13	3 14½	3 15½	2 14½	1 12½	0 10	½ 7	−½ 4½	1 2½	3 1½	AM	18	19
19	AM	5½ 1	8½ 1	11½ 1½	13½ 2	14½ 2	14½ 1½	13½ 1	11½ ½	9 0	6½ 0	4 ½	2 2	PM		
	PM	1 4	½ 7	½ 9½	1 12	1 13½	1 14½	1 14	½ 13	½ 10½	½ 8	1 5½	1½ 3½	AM	19	20
20	AM	3½ 2	5½ 1	8 0	10 0	12 ½	13½ 1	14 1	13½ 1	12 1	9½ 1	12 1	4½ 1½	PM		
	PM	2½ 2½	1 4	0 6	½ 8½	0 10½	½ 12½	1 13½	1 14	1½ 13	1½ 11	1½ 9	2 6½	AM	20	21
21	AM	2½ 3½	3½ 1½	5 0	7 ½	9 ½	11½ 0	13 1	13½ 1½	13½ 2	12 2½	10 2½	7½ 2	PM		
	PM	4½ 2½	2 3	½ 4	−½ 5½	1 7½	0 10	1 12	2 13	2½ 14	3 13	3 11½	3 9	AM	21	22
22	AM	2½ 6	2½ 3½	3 1	4 −½	6 1	8½ ½	11 ½	12½ 2	13½ 3½	13½ 4	12½ 4½	10 4	PM		
	PM	7 3	4 2½	1½ 2½	0 3	−1 4½	½ 7	1 9½	2½ 11½	4 13½	5 14	5½ 13½	5 11½	AM	22	23
23	AM	4 8½	3 5½	2½ 2½	2½ ½	3½ −½	5½ ½	8 1	10½ 2½	13 4½	14 6	14 6½	12 6	PM		
	PM	9½ 5	6½ 3½	3½ 2½	1 2	½ 2½	−½ 4	1 6½	3 9	5 12	6½ 13½	7½ 14	7½ 13	AM	23	24
24	AM	6 10½	4½ 7½	3 4	2 1½	2 0	3 0	5½ 1	8 3	11 5	13 7½	14 8½	13½ 8½	PM		
	PM	11½ 7½	8½ 5½	5 3½	2 2	0 1½	0 2	1 4	3 7	5½ 10	8 12½	9½ 14	10 13½	AM	24	25
25	AM	9 12	7 9	4½ 6	2½ 3	1 ½	1½ 0	3 1	6 3	9 5½	11½ 8½	13 10	13½ 11	PM		
	PM	12½ 10	10 8	6½ 5½	3 3	1 1½	0 1	1 2	3 4½	5½ 7½	8½ 10½	11 12½	12 13½	AM	25	26
26	AM	11 12½	9½ 10½	7 7	4 4	2 1½	1 0	1½ 1½	3½ 2½	6½ 5½	9½ 8½	12 11	13 12½	PM		
	PM	12½ 12½	10½ 11	7½ 8	4 5	1½ 2	½ 1	½ 1	2 2½	5 5	8½ 8	11 11	13 12½	AM	26	27
27	AM	13 12	11½ 11	9 8	5½ 5	3 2	1 ½	½ ½	2 2	4½ 5	7½ 8½	10 11½	12 13½	PM		
	PM	12 14	10½ 13	8 10	5 7	2 3½	½ 1½	½ ½	1½ 1½	4½ 3½	8 6	11½ 9	14 11	AM	27	28
28	AM	14½ 11½	13½ 10½	11 8½	8 5½	4½ 2½	2 ½	½ 0	1 1	2½ 4	5 7	8 11	10 13½	PM		
	PM	11 15	10 14½	8 12½	5½ 9	2½ 5½	½ 2½	0 1	1 ½	3½ 2	7 5	10½ 6½	13½ 9	AM	28	29
29	AM	15 10	15 10	13 8½	10 6	6½ 3	3½ 1	1 −½	½ ½	1 2½	3 6	5½ 9½	8 13	PM		
	PM	9 15	9½ 15½	8 14	5½ 11½	3 8	½ 4½	−½ 2	0 ½	2 1	5½ 2½	9 4½	12½ 6½	AM	29	30
30	AM	14½ 8	15½ 8½	14½ 7½	12 5½	8½ 3	5 1	2½ ½	1 ½	1 1½	2 4½	4 8	6 11½	PM		
	PM	7 14	7½ 15½	7 15	5 13	3 10	½ 6	½ 3	−½ 1½	1 1	3½ 1½	7 3	10½ 4½	AM	30	
31	AM													PM		
	PM													AM		

Table 2

Month: October 1958

		0 h		1 h.		2 h.		3 h.		4 h.		5 h.		6 h.		7 h		8 h		9 h.		10 h.		11 h				
		12 h.		13 h		14 h.		15 h		16 h		17 h.		18 h		19 h		20 h		21 h		22 h		23 h				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W	Dates	
Dates	15° E	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		East of 180	West of 180
1	AM	13½	6	15	7	15	6½	13½	5	10½	3	7	1	4	½	2	1	1	½	1	3	2	6	4	10	PM		1
	PM	5	13	6	14½	5½	15	4½	14	3	11½	1	8½	-½	5½	-1	3	0	1½	2	1½	5	2	9	3	AM	1	2
2	AM	12	4½	14	5	15	5	14	4	12½	3	9½	1	6½	-½	4	1	2	-½	1½	1½	1½	4	2½	7½	PM		
	PM	3½	11	4	13	4	14½	3½	14	2½	13	1	10½	-½	8	1	5	-½	3	1	2	3½	1½	6½	2	AM	2	3
3	AM	10	3	12½	3½	14	3½	14	3	13	2	11	1	8½	0	6	-1	4	-½	2½	½	2	3	2	5½	PM		
	PM	2½	8½	3	11	3	13	2½	14	2	13½	1	12	0	10	-½	7½	-½	5	½	3½	2½	2½	5	2	AM	3	4
4	AM	7½	2	10½	2	12½	2½	13½	2	13½	1½	12	1	11	0	9	0	6½	-½	4½	½	3	2	2	4	PM		
	PM	1½	6½	1½	9	1½	11	1½	12½	1½	13½	1	13	½	12	0	10	0	8	½	6	1½	4	3½	2½	AM	4	5
5	AM	5½	2	8	1½	10	1½	12	1½	13	1	13	1	12½	1	11	½	9	½	7	1	5	1½	3½	2½	PM		
	PM	2	4½	1½	6½	1	8½	1	10½	1	12	1½	13	1½	13	1	12	1	10½	1½	8½	2	6	2½	4	AM	5	6
6	AM	4	2½	5½	1½	7½	1	9½	½	11½	1	12½	1½	13	1½	13	2	11½	2	10	2	7½	2	5	2½	PM		
	PM	3	3	1½	4½	½	6	½	8	1	10	1½	12	2	13	3	13½	3	12½	3	11	3	9	3	6½	AM	6	7
7	AM	3	4	3½	2	5	1	7	½	9	½	11	1½	12½	2½	13½	3½	13½	4	12	4½	10	4	7½	3½	PM		
	PM	5	3	2½	3	1	3½	0	5	½	7	1½	9½	3	11½	4½	12	5	13	5½	12½	5	11½	4½	9	AM	7	8
8	AM	3½	6	3	3½	3	1	4	0	5½	0	8	1	10½	3	13	5	14	6	14	7	12½	7	10	6	PM		
	PM	7	4½	4	3	1½	2½	0	2½	0	4	1	6	3	9	5½	11½	7½	13½	8½	14	8½	13½	7½	11½	AM	8	9
9	AM	5½	8½	3½	5	2	2	1½	½	2½	0	4½	1	7	3	10	5½	13	8	14	9½	14	10	12½	9	PM		
	PM	9½	7	6	5	3	2½	½	1	½	1	½	2½	2½	5	5½	8½	8½	11½	10½	13½	11½	14	11	13	AM	9	10
10	AM	9	10½	6	7	3	3½	1	1	½	-½	1	0	3½	2	6½	5	10	8½	12½	11½	14	13	13½	13	PM		
	PM	11	11	8	8	4	4½	1	1½	-½	0	-½	0	1½	1½	5	4½	8½	8	12	11	14	13	14½	13½	AM	10	11
11	AM	13	12	10	9	6	5	2½	2	0	-½	-1	-1	0	½	2½	4	6	8	9½	12	12	14½	13	16	PM		
	PM	12	15	9	12	5½	8	2	4	0	½	-1	-1½	0	1	3	1	7	4	11½	7½	15	10	17	12	AM	11	12
12	AM	16½	11½	13½	9½	9½	6	5	2½	1	0	-1½	-1½	-2	½	½	2	2½	6½	6	11	9	15	11	17½	PM		
	PM	11	18	9½	16	6	12	3	7	0	3	-1½	1	-1	2	1	1½	5	½	10	4	15	7	18	9½	AM	12	13
13	AM	18½	10½	17	9	14	6½	9	3½	4	½	0	-1½	-2	1½	2½	0	1	4	2	8½	5	13½	8	17	PM		
	PM	9	19	8½	18½	6½	16	3½	11½	½	6½	-1½	2	-2	-1	½	2½	3	-2	7½	0	12½	3	17	6	AM		

15	PM	3 16½	4 18½	4½ 19	3 17	1½ 14	½ 9½	-2 5	-2 1½	-½ -1	2 -2	6 -1½	11½ 0	AM	15	16
16	AM	14½ 1½	17½ 3	18½ 3½	18 3	15 1½	11 0	7 -1½	3 -2	0 -1	-1 1½	-1½ 4½	-1 9	PM		
	PM	½ 13	2 16	2½ 18	2½ 17½	1½ 16	0 12½	-1 9	-1½ 5	-1 2	½ 0	3½ -1	7 -1	AM	16	17
17	AM	11 -½	14 1	16½ 1½	17 2	16 1½	14 ½	10½ -½	7 -1	3½ -1	1 ½	-½ 2½	-1 6	PM		
	PM	1 9	0 12½	½ 15	1 16	1 16	½ 14½	0 12	-½ 8½	0 5	½ 2½	2 ½	4½ ½	AM	17	18
18	AM	8 1	11 -½	13½ 0	15 ½	15½ 1	14 1	12 ½	10 ½	7 ½	4 1	1½ 2	0 4	PM		
	PM	-½ 6½	-1 9	-½ 11½	0 13½	½ 14	1 14	1 13	1 11	1½ 8	1½ 5½	2½ 3	4 1	AM	18	19
19	AM	5½ 0	8 ½	10 -½	12 0	13 ½	13½ 1	13 2	11½ 2	9½ 2½	7 2½	4 3	2 3½	PM		
	PM	½ 5	-½ 6½	-1 8½	½ 10	½ 11½	1½ 12½	2 13	3 12	3 10½	3½ 8	3½ 5½	4 3	AM	19	20
20	AM	4½ 1	5½ 0	7 ½	8½ -½	10 ½	11½ 1½	12 2½	12 3½	11 4½	9 4½	7 4½	4½ 4½	PM		
	PM	2 4½	½ 5	½ 6	-½ 7	0 8½	1½ 10	3 11½	4½ 12	5 11½	5½ 10	5½ 8	5 5½	AM	20	21
21	AM	5 3	5 1	5 0	6 -½	7 0	9 1½	10½ 3½	11½ 5	11½ 6½	10½ 7	9 7	6½ 6½	PM		
	PM	4 5½	2 5	½ 4½	0 5	0 6	1½ 7½	3½ 9	5½ 10½	7 11	8 11	8 9½	7½ 7½	AM	21	22
22	AM	6½ 5	5 2½	4½ 1	4 0	5 ½	6 1½	8 3½	9½ 6	10½ 8	11 9	10 9½	8 9	PM		
	PM	6 7½	3 5½	1 4½	0 3½	0 4	1½ 5	3½ 6½	6 8½	8½ 10	10 11	10½ 10½	10 9	AM	22	23
23	AM	8½ 6½	6½ 4	5 2	3½ ½	3 0	4 1	5½ 3½	7½ 6	9 9	10½ 11	10½ 12	9 11½	PM		
	PM	7 10	4½ 7½	2 5	½ 3½	0 2½	1 3	3 4½	6 6	9 8½	11½ 10	12½ 10½	12½ 9½	AM	23	24
24	AM	11 7½	8½ 5	6 2½	3½ ½	2 0	2 1	3 3	5 6	7½ 9½	9 12	10 13½	9½ 13½	PM		
	PM	7½ 12	5½ 9½	3 6½	1 4	0 2	½ 1½	2½ 2½	6 4	9 6½	12 8½	14 9½	14½ 9½	AM	24	25
25	AM	13 8	11 5½	7½ 3	4½ 1	2 0	1 0	1½ 2	3 5	5½ 9	7½ 12½	9 14½	9 15½	PM		
	PM	8 14½	6 12	3½ 9	1 5	0 2½	0 1	1½ 1	4½ 2	8½ 4	12 6½	14½ 8	16 8½	AM	25	26
26	AM	15½ 8	13 6	10 4	6 1½	3 0	1 ½	½ 1	1 4	3 8	5½ 11½	7 14½	8 16½	PM		
	PM	7½ 16	6 14	3½ 11	1 7	-½ 3½	-1 1	½ 0	3 ½	7 2	11 4	14 6	16½ 7½	AM	26	27
27	AM	16½ 7	15 6	12 4	8 1½	4 -½	1 1	0 0	0 2½	1 6	3 10½	5 14	6½ 16½	PM		
	PM	7 17	5½ 16	4 13	1½ 9	-½ 5	1½ 2	-½ 0	1½ ½	5 ½	9½ 2	13½ 4	16 5½	AM	27	28
28	AM	17 6	16½ 5½	14 4	10 1½	6 -½	2½ -1½	0 -1	-1 1	0 4½	1 8½	3 12½	4½ 16	PM		
	PM	5½ 17½	5 17	3½ 14½	1½ 11	-½ 7	-1½ 3	-1½ ½	0 1	3½ -½	7½ ½	11½ 2	15 4	AM	28	29
29	AM	17 4½	17 4½	15½ 3½	12 2	8 0	4 -1½	1 -1½	-½ 0	-1 2½	0 6½	1 10½	3 14½	PM		
	PM	4 17	4 17½	3 16	1½ 13	0 9½	-1½ 5½	-2 2	-1 0	2 -1	5½ -½	9½ ½	13½ 2	AM	29	30
30	AM	16 3	17 3½	16½ 3	14 1½	10 0	6 -1½	3 -2	½ -1	-1 1	-1 4½	0 8½	1½ 12	PM		
	PM	2½ 15½	3 17	2½ 17	1 15	0 12	-1½ 8	-2 4	-1½ 1½	1 -½	5 -1	8 -½	11½ ½	AM	30	31
31	AM	14½ 1½	16½ 2½	16½ 2	15 1½	12 0	8½ -1	5 -2	2 -1½	0 0	½ 2½	-½ 6	0 10	PM		
	PM	1 13½	1½ 15½	1½ 16½	1 16	0 13½	-1 10	-2 7	-1½ 3½	0 1	2 0	5½ -½	9 0	AM		

Table 2

Month: November 1958

		0 h		1 h		2 h		3 h		4 h		5 h		6 h.		7 h		8 h		9 h		10 h		11 h				
		12 h		13 h		14 h		15 h		16 h		17 h		18 h		19 h		20 h		21 h		22 h		23 h				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W	Dates East of 180	West of 180
15° E Dates		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S			
1	AM	12 ½	½	15	1	16	1 ½	16	1	14	½	11	- ½	8	- 1 ½	4 ½	- 1 ½	2	- ½	½	1 ½	- ½	4	½	7 ½	PM		1
	PM	½	11	1	13 ½	1	15 ½	1	15 ½	½	14 ½	0	12 ½	- 1	9 ½	1	6	0	3 ½	1 ½	1 ½	4	0	7	0	AM	1	2
2	AM	10	0	13	½	14 ½	1	15 ½	1	14 ½	1	12 ½	0	10	0	7	- ½	4	0	2	1	½	3	0	6	PM		
	PM	0	9	½	11 ½	1	13 ½	1	14 ½	1	14 ½	1	13 ½	½	11	0	8 ½	½	6	1 ½	3 ½	3	1 ½	5	½	AM	2	3
3	AM	8	0	10	0	12 ½	½	14	1	14	1 ½	13 ½	1 ½	12	1 ½	9 ½	1 ½	7	1 ½	4 ½	2	2 ½	3	1	4 ½	PM		
	PM	0	6 ½	0	9	½	11	1	12 ½	1 ½	13 ½	2	13 ½	2 ½	12 ½	2 ½	11	2 ½	8 ½	2 ½	6	3	3 ½	4	1 ½	AM	3	4
4	AM	5 ½	½	7 ½	0	9 ½	½	11	1	12 ½	2	13	2 ½	13	3	11 ½	3 ½	9 ½	3 ½	7	3 ½	4 ½	3 ½	2	4	PM		
	PM	1	5	0	6	0	8	1	9 ½	2	11	3	12	4	12 ½	5	12	5	10 ½	5	8	4 ½	6	4 ½	3 ½	AM	4	5
5	AM	4 ½	1	5 ½	0	6 ½	0	8	½	9 ½	2	11	3 ½	12	5	12	6	11	6 ½	9	6 ½	6 ½	6	4	5	PM		
	PM	2	4 ½	½	4 ½	0	5	½	6 ½	2	8	3 ½	10	5 ½	11	7	12	8	11	8	10	7	7 ½	6	5	AM	5	6
6	AM	5	2 ½	4	½	4	0	5	0	6	1 ½	8	3 ½	10	6	11	8	11	9 ½	10 ½	10	8 ½	9	6	7 ½	PM		
	PM	3	6	1	4	0	3 ½	0	3 ½	1	4 ½	3	6	6	8	9	10	10 ½	11	11 ½	10 ½	11	9	9	6 ½	AM	6	7
7	AM	7	4	5	1 ½	3	0	2 ½	½	3	0	4	2 ½	6 ½	6	8 ½	9	10	11 ½	10 ½	13	9 ½	13	7	11	PM		
	PM	4 ½	9	2	6	0	3 ½	1	1 ½	½	1 ½	2	2 ½	5	4 ½	9	7	12	9	14	10	14 ½	9 ½	13	8	AM	7	8
8	AM	10 ½	5	7	2	4	0	1 ½	1 ½	½	- 1	1	1	2 ½	4 ½	5	8 ½	7 ½	12 ½	9	15	9	16	8	15	PM		
	PM	5 ½	12 ½	2 ½	9	0	5	- 1 ½	2	- 1 ½	0	0	- ½	4	1	8	3	12 ½	5 ½	15 ½	7 ½	17	8 ½	17	8	AM	8	9
9	AM	14 ½	6	11	3	6 ½	½	2 ½	1 ½	0	- 2	- 1 ½	- 1	- 1	2 ½	1	7	4	11 ½	6	15 ½	7 ½	18	7 ½	18 ½	PM		
	PM	6	17	3 ½	13	½	8 ½	- 1	4	- 2 ½	0	- 1 ½	- 2	2	- 2	5 ½	- ½	11	2	15	4 ½	18 ½	6	19 ½	7	AM	9	10
10	AM	18 ½	6	15	4	10 ½	1	5 ½	- 1 ½	1	- 3	- 2	2 ½	- 3	0	- 2	4	0	9	3	14	5	18	6	20	PM		
	PM	5 ½	20	4	17 ½	1	13	1	7 ½	3	2 ½	- 3	1	- 1	3	2 ½	3	8	1 ½	13	1	17 ½	3	20 ½	5	AM	10	11
11	AM	21	5	19	4	14 ½	1 ½	9	- 1	4	- 3	½	3 ½	- 3	2	4	1	- 2 ½	6	½	11 ½	2	16 ½	3 ½	20	PM		
	PM	4 ½	21 ½	3 ½	20	1 ½	16 ½	- 1	11 ½	- 3	6	- 3 ½	1	- 3	- 2 ½	0	- 4	4 ½	- 3 ½	10	2	15	½	19	2 ½	AM	11	12
12	AM	21	3 ½	21	3 ½	18	2	13	0	8	- 2 ½	3	- 3 ½	- 1	- 3 ½	- 3 ½	- 1	- 4	3	3	8	- 1	13	1	17 ½	PM		
	PM	2 ½	20 ½	3	21	2	19	0	15	2	10	3 ½	5	- 3 ½	0	2	- 3	1 ½	- 4	6 ½	- 3 ½	11 ½	2	16 ½	0	AM	12	13
13	AM	19 ½	1 ½	21	2 ½	19 ½	2	16 ½	½	12	1 ½	6 ½	- 3	2	3 ½	- 1 ½	- 2 ½	- 3 ½	½	- 4	4 ½	- 3	9	- 1	14	PM		
	PM	½	18	1 ½	20	1 ½	20	½	17 ½	- 1	13 ½	- 2 ½	9	- 3	4	2 ½	0	0	2 ½	3	- 3 ½	7 ½	- 3	12 ½	- 2	AM	13	14

15	AM	13 1 1/2	16 0	17 1/2 1	17 1	15 1/2	12 0	8 - 1/2	4 1/2 - 1	1 0	- 1 1 1/2	- 2 1/2 4	- 2 1/2 7 1/2			
	PM	- 1 1/2 11	- 1/2 14	1/2 16	1 16 1/2	1 15 1/2	1/2 13	0 9 1/2	0 6	1/2 2 1/2	1 1/2 0	3 1/2 - 1 1/2	6 1/2 - 2	AM	15	16
16	AM	9 1/2 - 2	12 - 1	14 1/2 1/2	15 1 1/2	15 1 1/2	13 1 1/2	10 1 1/2	7 1	4 1	1 2	- 1/2 3 1/2	- 1 1/2 5 1/2	PM		
	PM	- 1 1/2 8	- 1 10 1/2	0 13	1 14	2 14	2 1/2 13	2 1/2 11	2 8	2 1/2 5	3 2 1/2	3 1/2 1/2	5 - 1	AM	16	17
17	AM	7 - 1 1/2	9 - 1	11 0	12 1/2 1	13 2	12 1/2 3	11 3 1/2	9 3 1/2	6 1/2 3 1/2	4 4	1 1/2 4	0 5	PM		
	PM	1 6 1/2	- 1 8	0 9 1/2	1 11	2 12	3 1/2 12	4 11	4 1/2 9 1/2	5 7	5 4 1/2	5 2 1/2	5 1/2 1/2	AM	17	18
18	AM	6 - 1/2	7 - 1	8 1/2 0	9 1/2 1	10 1/2 2 1/2	11 4	10 5	9 1/2 6	8 6	5 1/2 6	3 1/2 6	1 1/2 6	PM		
	PM	0 6	- 1/2 6 1/2	0 7	1 8	2 1/2 9	4 10	5 1/2 10	6 1/2 9 1/2	7 8	7 1/2 6	7 5 1/2	6 1/2 2	AM	18	19
19	AM	6 1/2	6 0	6 1/2 0	7 1/2	8 2	8 1/2 4	9 6	9 7 1/2	8 8 1/2	7 8 1/2	5 8	3 7 1/2	PM		
	PM	1 6 1/2	0 6	0 5 1/2	1/2 6	2 6 1/2	4 7 1/2	6 8	8 8 1/2	9 1/2 8	10 7	9 1/2 5 1/2	8 1/2 3 1/2	AM	19	20
20	AM	7 1 1/2	6 1/2	5 1/2 0	5 1/2	5 1/2 2	6 1/2 4	7 6 1/2	8 8 1/2	8 10 1/2	7 11	5 1/2 11	4 10	PM		
	PM	2 8	1/2 6 1/2	0 5	0 4 1/2	1 1/2 4 1/2	3 1/2 5	6 1/2 6	9 7	11 7 1/2	12 7	12 6	11 4 1/2	AM	20	21
21	AM	9 2 1/2	7 1	5 0	4 0	3 1/2 1	4 3	5 6	6 9	7 11 1/2	7 13	6 13	4 1/2 12	PM		
	PM	2 1/2 10	1 8	0 5 1/2	1/2 4	1/2 3	2 1/2 3	5 1/2 4	9 5	11 1/2 6	13 1/2 6 1/2	14 6	13 5	AM	21	22
22	AM	11 3	8 1/2 1	6 0	4 1	2 1/2 0	2 2	3 5	4 8 1/2	5 12	6 14	5 1/2 15	5 14 1/2	PM		
	PM	3 12	1 9 1/2	0 6 1/2	- 1 4	- 1/2 2	1 1/2 1 1/2	4 1/2 2	8 3	11 1/2 4	14 5	15 1/2 5 1/2	15 5	AM	22	23
23	AM	13 1/2 3	10 1/2 1 1/2	7 0	4 - 1	2 1	1/2 1	1 3 1/2	2 7 1/2	3 1/2 11	4 1/2 14	5 16	4 1/2 16	PM		
	PM	3 14 1/2	1 1/2 12	0 8	- 1 1/2 4 1/2	- 1 1/2 2	0 1/2	3 0	6 1/2 1	10 1/2 2 1/2	14 3 1/2	16 4 1/2	16 1/2 4 1/2	AM	23	24
24	AM	15 1/2 3 1/2	13 1 1/2	9 0	5 1/2 - 1 1/2	2 2	0 1	1/2 2	0 5 1/2	1 1/2 10	3 13 1/2	4 16	4 17 1/2	PM		
	PM	3 16 1/2	2 14	0 10	- 1 1/2 6	- 2 2 1/2	1 1/2 0	1 - 1	5 - 1	9 1/2	13 2	16 3	17 1/2 3 1/2	AM	24	25
25	AM	17 3	15 1 1/2	11 0	7 - 2	3 2 1/2	0 - 2	1 1/2 0	- 1 1/2 3 1/2	- 1/2 8	1 12 1/2	2 16	3 18	PM		
	PM	3 17 1/2	2 16	0 12	- 1 1/2 8	- 2 1/2 4	- 2 1/2 1/2	- 1/2 - 1 1/2	2 1/2 - 2	7 - 1 1/2	11 1/2 0	15 1 1/2	17 1/2 2 1/2	AM	25	26
26	AM	18 2 1/2	16 1/2 1 1/2	13 0	9 - 1 1/2	5 - 3	1 - 3	- 1 1/2 - 1 1/2	- 2 1/2 1 1/2	- 2 6	- 1 10 1/2	1/2 14 1/2	2 17 1/2	PM		
	PM	2 18 1/2	1 1/2 17 1/2	0 14 1/2	- 1 1/2 10 1/2	- 3 6	- 3 2	- 2 - 1	1 - 2 1/2	5 - 2 1/2	9 1/2 - 1 1/2	14 0	17 1	AM	26	27
27	AM	18 1/2 2	18 1 1/2	15 1/2 1/2	11 1/2 - 1	7 - 2 1/2	3 - 3	- 1/2 - 2 1/2	- 2 1/2 0	- 3 4	2 8 1/2	- 1 13	1/2 16 1/2	PM		
	PM	1 1/2 18	1 18 1/2	0 16	- 1 12 1/2	- 2 1/2 8	- 3 3 1/2	- 2 1/2 0	- 1/2 - 2	3 - 2 1/2	7 - 2	11 1/2 - 1	15 1/2 0	AM	27	28
28	AM	18 1	18 1/2 1	17 1/2	14 - 1	10 - 2	5 1/2 - 3	1 1/2 - 3	- 1 - 1	- 2 1/2 2	- 2 1/2 6	- 2 10 1/2	- 1/2 14 1/2	PM		
	PM	1/2 17 1/2	1 18 1/2	1/2 17 1/2	- 1/2 15	- 2 11	- 3 6 1/2	3 2 1/2	- 1 1/2 - 1/2	1 - 2	5 - 2 1/2	9 - 2	13 - 1	AM	28	29
29	AM	17 1/2	18 1	17 1/2 1	15 1/2 0	12 - 1 1/2	7 1/2 - 2 1/2	3 1/2 2 1/2	1/2 - 1 1/2	1 1/2 1/2	- 2 1/2 4	- 2 8	- 1 12	PM		
	PM	0 15 1/2	1/2 17 1/2	1 18	0 16	- 1 13	- 2 9	2 1/2 5	- 1 1/2 1 1/2	0 - 1	3 1/2 - 2	7 - 2	11 - 1	AM	29	30
30	AM	14 1/2 0	17 1	17 1/2 1	16 1/2 1	14 0	10 - 1	6 1 1/2	2 1/2 - 1 1/2	0 0	- 1 1/2 2 1/2	- 2 6	- 1 1/2 9 1/2	PM		
	PM	- 1/2 13	1/2 15 1/2	1 1/2 17	1 1/2 16 1/2	1/2 14 1/2	0 11 1/2	- 1 7 1/2	1 4	0 1	2 - 1	5 1 1/2	8 1/2 1 1/2	AM	30	
31	AM													PM		
	PM													AM		

Table 2

Month: December 1958

		0 h		1 h		2 h		3 h		4 h		5 h		6 h		7 h		8 h		9 h		10 h		11 h				
		12 h		13 h		14 h		15 h		16 h		17 h		18 h		19 h		20 h		21 h		22 h		23 h				
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	165° W	Dates	
15° E		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		East of 180	West of 180
Dates 1	AM	12	-½	14½	½	16	1½	16	2	14½	1½	12	1	8½	½	5	0	2	½	0	2	1	4	-1½	7	PM		1
	PM	-½	10½	½	13	1½	15	2	15½	2½	14½	2	12½	1½	9½	1	6½	1	3½	2	1	4	½	6	1	AM	1	2
2	AM	9	-½	12	½	13½	1½	14½	2½	14½	3	13	3	10½	2½	7	2½	4	2	1½	2½	0	3½	-1	5	PM		
	PM	-½	7½	0	10	1½	12	3	13	3½	13½	4	12½	4	11	3½	8	3½	5½	3½	3	4	½	5	-½	AM	2	3
3	AM	6½	½	8½	0	10½	1½	12	3	12½	4	12	5	11	5½	8½	5½	6	5	3½	4½	1½	4½	0	5	PM		
	PM	½	5½	0	7	1	8½	3	10	4½	11	6	11½	7	11	7	9	6½	7	6	4½	5½	2	5	0	AM	3	4
4	AM	5	½	6	-½	7	½	8	2½	9½	4½	10	6	10	7½	9	8½	7	8½	5	7½	2½	6½	½	5½	PM		
	PM	½	5	-1	5	0	5½	2	6½	4	7½	6½	8½	8½	9	10	8½	10	7½	9½	5½	8	3	7	1	AM	4	5
5	AM	5½	-½	4½	-1	4½	-½	5	1	6	3½	7	6	8	9	8	11	7	11½	6	11½	4	10	1½	8	PM		
	PM	0	6½	-1	4½	-1	3½	0	3½	2½	4	6	5	9	6	11½	7	13	7	13	6	12	4	10	2	AM	5	6
6	AM	7½	0	5	1½	3½	-1½	2½	-½	2½	1½	3	5	4½	8½	5½	12	6	14	5½	15	4	14	2	12	PM		
	PM	0	9½	1½	6	-2	3½	-1½	1½	½	1	4	1½	8	2½	12	4	14½	5	16	5	16	4½	14	2½	AM	6	7
7	AM	11	½	7½	-1½	4	-2½	1½	2	0	½	0	3	1	7	2½	11	3½	15	4½	17	4	17½	2½	16	PM		
	PM	½	13	-1	9	-2½	5	-3	1½	-1½	-½	1½	-1½	5½	-½	10	½	14½	2	17½	3½	18½	3½	18	2½	AM	7	8
8	AM	15	1	11	1	6½	-3	2½	-3½	-1	-2½	-2	0	2	4	-1	9	1	14	2	17½	3	19½	2½	19	PM		
	PM	1	17	-1	13	-2½	8	4	3½	-3½	0	1½	-2½	2½	3	7½	-2½	12½	-½	17	1	19½	2	20½	2½	AM	8	9
9	AM	19	1½	15	0	10½	-2½	5	-4	½	-4	-2½	2½	-4	1	-3½	5½	-2	11	0	16	1½	19½	2	21	PM		
	PM	1½	20	0	17	-2	12	-4	7	-4½	2½	-3½	-2	1	4	3½	4	9	3	14½	1½	18½	½	21½	1½	AM	9	10
10	AM	21	1½	18½	½	14	1½	8½	3½	3½	-4½	-1	-4	-4	-2	-5	2	-4	7	2½	13	½	17½	1	20½	PM		
	PM	1½	21½	½	20	-1	16	3	11	4½	5½	4½	0	3	-3	½	4½	5½	-4½	11	3½	16	-1½	20	½	AM	10	11
11	AM	21½	1	20½	1	17	-½	12	-2	7	-4	2	-4½	2	-3½	4½	-1	-5	3½	4	8½	-2	14	0	18	PM		
	PM	1	21	1	21	0	18½	1½	14½	-3	9	-4	3½	3½	1	1½	-4	2	-5	7½	4½	12½	3	17	-1	AM	11	12
12	AM	20	1	20½	1½	19	1	15½	-½	10½	-2	5	-3½	½	-3½	-3	-2	-4½	1	-4½	5½	-3	10	1½	15	PM		
	PM	½	18½	1	20	1	19	0	16½	-1½	12	-3	7	3	2	-2	-1½	0	-3½	4	4	9	-3½	13	-2	AM	12	13
13	AM	17	0	19	1½	19	1½	16½	1	13	0	8	-1½	3½	2½	0	-2	3	0	-4	3	3	7	2	11½	PM		
	PM	0	15½	1	17½	2	18	2	16½	½	13½	-½	9	1	5	-1	1	0	-2	2½	-3	6	-3	10	-2	AM	13	14

15	PM	−½ 9	1 11½	2½ 13	3½ 14	4½ 13	4 11½	4 8½	3 5½	3 2½	3½ 0	4 −1	6 −1½	AM	15	16
16	AM	8 ½	10½ 1	12 2½	12½ 4	12½ 5	11 5½	8½ 5	5½ 4½	3 4½	1 4	−½ 5	−1 6	PM		
	PM	−½ 7½	½ 9	2½ 10½	4 11½	5 11½	6 10½	6 9	6 6½	5½ 4	5 1½	5½ 0	6 −½	AM	16	17
17	AM	7 −½	8 ½	9 2	10 4	10½ 5½	10 6½	8½ 7	6½ 7½	4 7	2 6½	½ 6	−½ 6½	PM		
	PM	−½ 6½	0 7	2 8	3½ 9	5 9	7 9	8 8	8 6½	8 5	7½ 3	7 1	7 0	AM	17	18
18	AM	6½ −½	7 0	7 1	7½ 3	8 5	8 7	7½ 8	6 9	4½ 9½	3 9	1½ 8½	0 7½	PM		
	PM	½ 7	0 6½	1 6½	2½ 6½	4½ 7	7 7	8½ 7	10 6	10½ 5	10 3½	9½ 2	8½ ½	AM	18	19
19	AM	7 −½	6½ −½	6 ½	5½ 2	6 4	6 6½	6 9	5½ 10½	4½ 11½	3½ 11½	2 10½	½ 9	PM		
	PM	½ 8	½ 6½	0 5½	1½ 5	3½ 4½	6 5	9 5	11 5	12 4½	12 3½	11½ 2	10 1	AM	19	20
20	AM	8½ 0	6½ −1	5 −½	4 1	3½ 3	3½ 5½	4 8	4 10½	4 12½	3½ 13	2 13	1 11½	PM		
	PM	0 9½	−1 7	−1 5½	0 3½	2 3	5 2½	8 3	10½ 3½	13 3½	14 3	13½ 2½	12½ 1	AM	20	21
21	AM	10 0	8 −1	5 −1½	3 ½	2 1	1½ 3½	2 7	2½ 10	3 13	3 14½	2½ 15	1 13½	PM		
	PM	0 11½	1 8½	1½ 5½	−1 3	0 1½	3 1	6½ 1	10 1½	13 2	15 2½	15½ 2½	14½ 1½	AM	21	22
22	AM	12 0	9 −1	6 −2	3 −2	1 ½	0 2	0 5½	½ 9	1½ 12½	2 15	2 16	1½ 15½	PM		
	PM	0 13½	−1 10½	2 7	−2 3½	−1½ 1	1 ½	4 −1	8 −½	12 ½	15 1½	16½ 2	16½ 1½	AM	22	23
23	AM	14½ ½	11½ −1	8 −2	4 −2½	1 −2	−1 0	−1½ 3	1 7	0 11½	1 14½	1½ 17	1½ 17	PM		
	PM	½ 16	−1 13	−2 9	−3 5	−2½ 1½	−1 −1	2 −2	6 −2	10½ −1	14 0	17 1	18 1½	AM	23	24
24	AM	17 ½	14 −½	10 −2	6 −3	2 −3	−1 −1½	−2½ 1	−2 5	−2 9½	−½ 13½	½ 17	1 18	PM		
	PM	½ 17½	−1 15½	−2 11½	3 7	3½ 3	−2½ −½	0 2½	4 3	8½ −2½	13 −1	16½ 0	18½ 1	AM	24	25
25	AM	18½ 1	16 0	12½ −1½	8 −3	3½ −3½	0 3½	−2½ −1	3½ 3	3 7½	−1½ 12	0 16	½ 18½	PM		
	PM	1 19	0 17½	−1 14	2½ 10	−3½ 5	−3 1	−1½ −2	2 −3½	6 −3	11 −2	15 −½	18 ½	AM	25	26
26	AM	19½ 1	18 ½	15 −½	11 −2	6 −3	1½ −3½	−1½ −2	−3 ½	3½ 5	2½ 9½	−1 14	0 17½	PM		
	PM	1 19½	1 19	0 16½	−1½ 12½	−3 7½	−3½ 3	−2½ −½	0 −3	4 −3½	8½ 3	13 −1½	17 0	AM	26	27
27	AM	19 1	19½ 1½	17 ½	14 −1	9 −2	4 −3	0 −2½	2 −1	−3½ 2½	−3 7	1½ 11½	0 16	PM		
	PM	1½ 18½	2 19½	1 18	0 15	1½ 10½	2½ 6	−2½ 1½	−1 1½	2 −3	6 −3	10½ −1½	15 0	AM	27	28
28	AM	18 1½	19 2	18 2	15½ 1	11½ −½	6½ −2	2½ −2½	−½ −1½	−2½ 1	−3 4½	−1½ 9	0 13	PM		
	PM	1½ 17	2½ 18½	2½ 18½	1½ 16	½ 12½	−1 8	−2 4	1½ 0	½ −2	4 −2½	8 1½	12 0	AM	28	29
29	AM	15½ 1½	18 3	18 3½	16½ 3	13 1½	9 0	5 −1	1 −1	−1 0	−2 2½	−2 6	0 10	PM		
	PM	1½ 14	3 16½	4 17½	4 16½	3 14	1½ 10	0 6	½ 2½	½ 0	2 −1½	5 −1½	9 −½	AM	29	30
30	AM	12½ 1½	15 3	16½ 4½	16 4½	14 4	11 3	7 1½	3 1	½ 1	−1 2	1½ 4	½ 7	PM		
	PM	1 10½	3 13	4½ 15	5½ 15	5½ 14	4½ 11	3 8	2 4	1½ 1	2½ 1	4 1½	6 ½	AM	30	31
31	AM	9 1	12 3	13½ 5	14 6	13½ 6	11 5½	8 4½	5 3½	1½ 3	0 3	−1 3½	−1 5½	PM		
	PM	½ 8	2½ 10	4½ 12	6 13	7 12½	7 10½	6 8	5 5	4 2½	3½ 0	4 −1	5 −1	AM		

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		0 h		1 h.		2 h		3 h		4 h		5 h		6 h		7 h		8 h		9 h		10 h		11 h			
		12 h		13 h		14 h		15 h		16 h.		17 h		18 h		19 h		20 h		21 h		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	**105 E**	
75 W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	10½	-1½	7½	2	5	-2	2½	1	1	1	½	4	½	7½	1	11	1½	13½	1½	15	1	15½	0	14	PM	Dates 1
	PM	-1	12	-2	9	2½	5	-2	2	0	½	2½	-½	6	½	10	0	13½	1	16	1	16½	1	15½	0	AM	2
2	AM	13	-1	10	2	6	3	3	2½	½	-1	1	1½	1½	5	1	9	0	13	½	16	1	17	½	17	PM	
	PM	½	15	-2	11	3	7	3½	3	2½	0	0	-2	3½	-2	8	2	12	1	16	0	18	1	18	½	AM	3
3	AM	16	0	13	2	9	3	4½	3½	1	-3	-1½	-1	-3	2½	-2½	7	-1½	11½	½	15½	½	18	1	19	PM	
	PM	0	18	-1½	14½	3	10½	-4	5½	4	1½	2	1½	1	3	5	-3	10	2	14½	-1	18	½	19½	1	AM	4
4	AM	19	½	16½	1	12	2½	7½	4	3	4	-1	3	-3	0	-3½	4	-3	9	-1½	14	0	18	1	20	PM	
	PM	1	20	0	17½	2	13	3½	8½	-4	3½	-3½	-½	-1½	3	2	4	7	3	12	1½	16½	0	19½	1	AM	5
5	AM	20½	1½	19	½	16	-1	11	3	5½	4	1	-4	2	2½	-4	1	3½	6	-2½	11	½	16	1	19½	PM	
	PM	2	20	1½	19	0	16½	-2	12	3½	6½	-4	2	-3½	-2	-½	3½	3½	4	8½	2½	13½	-½	18	1	AM	6
6	AM	20½	2	20½	2½	18½	1	14½	1	9	-3	4	-3½	0	3½	-3	-1	4	3	3	7½	1	12½	1	17	PM	
	PM	2½	20	3	20½	2	19	0	15	1½	10	-3	5	-3½	½	-2	2½	½	-3½	5	3	10	-1	15	1	AM	7
7	AM	19	3	20½	3½	19	3	16	1½	11½	-½	6	2	2	3	1½	-2	3	½	3	5	-1½	9½	1	14½	PM	
	PM	3	18	4	19½	4	19	3	16	1	12	-1	7	-2	2½	-2	-1	0	-3	3	3	7	-1½	12	1	AM	8
8	AM	15½	3	18	4½	18½	5	17	4	13½	2½	9	½	4½	-1	1	1	-2	0	2½	2	2	6	0	10½	PM	
	PM	2½	14	4½	17	5½	18	5½	16½	4½	13½	2½	9½	1	5	0	1½	0	-1	1½	2	4	1½	8	0	AM	9
9	AM	11½	2½	14½	5	16½	6	16	6½	14	6	11	4	7½	2½	3	1	0	½	1½	1½	2	3½	-½	7	PM	
	PM	2	10	4	13	6	15	7	15	7	13½	6	10½	4½	7	3	3½	2	½	2	-1	3	1½	5	½	AM	10
10	AM	8½	2	11	4½	13	6½	13½	8	13	8	10½	7½	7½	6	4	4½	1	3	½	3	-1½	3½	½	4½	PM	
	PM	1	7	3½	9	6	11	8	12	9	11½	9	10	8	7½	6½	4½	5	2	4	0	3½	-1	4½	-1	AM	11
11	AM	5½	½	7½	3	9	5½	10	8	10	9	9	10	7½	9½	5	8	2½	7	0	5½	-1	4½	-1	4½	PM	
	PM	0	5	2	6	4½	7	7	8	9	8½	10½	8	11	6½	10	5	9	2½	7½	½	6	½	5	-1	AM	12
12	AM	4½	½	5	1½	5½	4	6	6½	6½	9	6½	10½	6½	11½	4½	11½	3	10½	1	9	½	7½	1	6	PM	
	PM	-1	5	½	4½	2½	4½	5	4½	8	5	10	5	12	4½	12½	4	12	2½	11	1	9½	0	7	-1	AM	13
13	AM	5½	1	4	0	3½	2	3	4½	3½	7	3½	10	3½	12	3	13½	2	13½	1	12½	0	11	-1	8½	PM	
	PM	1½	6	-1	4½	½	3	3	2	6	2	9	2	12	2½	14	2½	14½	2	14	1	13	0	10½	1	AM	14

15	AM	11 -1½	7½ -2	4 -1½	1½ -½	-½ 2	-1½ 5	-1½ 9	-1 12½	0 15	½ 17	½ 17	-½ 15½	PM	15
	PM	-1 12½	-2 9	2½ 5	1½ 1½	½ -½	3½ -2	7 -2	11 1½	14½ -½	17 0	18 -½	17 0	AM	16
16	AM	14 -1	10½ -2	6 2½	2½ -2	½ -½	-2 2	-2½ 6	-2 10	1 14	0 17	½ 18	0 17½	PM	
	PM	-½ 15	1½ 12	2½ 7½	2½ 3	-1½ 0	1 -2	4 -3	8½ -2½	12½ -2	16 ½	18 ½	18½ ½	AM	17
17	AM	16½ 0	13½ 1	9 -2	5 -2½	1 2	-2 -½	-3 3	-3 7	2 11	-1 15	½ 18	1 19	PM	
	PM	½ 17½	½ 14½	-2 10½	2½ 6	-2½ 1½	-1½ -1½	1 -3	5 -3	9½ 2½	14 1	17 ½	19 1½	AM	18
18	AM	18½ 1½	16 ½	12 -1	7 2	3 -2½	½ -2	3 0	-3½ 4	-3 8	-1 12½	½ 16½	2 18½	PM	
	PM	2 18½	1 17	0 13	2 8½	-2½ 4	-2½ 0	-½ -2½	2½ -3	6½ 3	11 -1	15 ½	18 2	AM	19
19	AM	18½ 2½	17 2	14 ½	9½ -1	5 -2	1 -2½	-2 -1	-3 2	-2½ 6	-1 10½	1 15	2½ 17½	PM	
	PM	3½ 18½	3 17½	1½ 14½	0 10	-1½ 6	-2 1½	-1½ -1½	1 -2½	4½ -2½	9 -1	13 1	16½ 3	AM	20
20	AM	18 4	18 4	15½ 3	11 1	7 -½	3 1½	½ -1½	-2 ½	2½ 4	-1½ 8	½ 12	3 15½	PM	
	PM	4 17½	4½ 17½	4 16	2 12	½ 8	-1 3½	-1½ 0	0 -2	2½ -2	6 1	10½ 1	14 3	AM	21
21	AM	16½ 4½	17½ 5½	16 5	13 3½	9 1½	4½ 0	1 -½	1 0	-2 2	-1 5½	½ 9½	3 13	PM	
	PM	5 16	6 17	6 16	4½ 13	3 9½	1 5½	0 2	0 -1	1½ -1½	4½ -1	8 ½	12 3	AM	22
22	AM	15 5	16 6½	15½ 6½	13 5½	10 4	6 2	2 1	0 ½	-1½ 2	-1 4	½ 7½	3 11	PM	
	PM	5 14	6½ 15½	7 15	7½ 13½	5 10½	3 6½	1½ 3	1 0	2 1	4 -1	7 ½	10 2½	AM	23
23	AM	12½ 5	14½ 6½	14½ 7½	13½ 7	10½ 6	7 4½	4 3	1 2	½ 2	-1 3½	0 6	2 9	PM	
	PM	4½ 11½	6½ 13½	8 14	8 13	7 10½	5½ 7½	4 4	3 1½	2½ -½	3½ 1	5½ 0	[illegible] 2	AM	24
24	AM	10½ 4	12 6	13 8	12½ 8½	10½ 8	8 6½	5 5	2 4	0 3½	-½ 4	0 5	1½ 7	PM	
	PM	3½ 9	6 11	7½ 12	8½ 11½	8½ 10	7½ 8	6 5	5 2½	4 ½	4 -½	5 0	6½ 1	AM	25
25	AM	8½ 3½	10 5½	11 7½	10½ 8½	9½ 9	7½ 8	5 7	2½ 6	½ 5	½ 4½	-½ 5	1 6	PM	
	PM	3 7½	5 9	7 10	8½ 10	9 9	9 7	8 5	7 2½	6 ½	5½ -½	5½ ½	6 ½	AM	26
26	AM	7 2	8 4½	8½ 6½	8½ 8	8 9	6½ 9½	5 9	3 8	1 7	0 6	-½ 6	0 6	PM	
	PM	1½ 6½	3½ 7	5½ 7½	7½ 7½	9 7	9½ 6	9½ 4½	9 3	8 1	7 0	6½ 1	6 -½	AM	27
27	AM	6 1	6 2½	6½ 5	6½ 7	6 9	5½ 10	4 10½	2½ 10	1 9	0 8	-½ 7	-½ 6½	PM	
	PM	0 6	1½ 5½	4 5½	6 5½	8 5	9½ 4½	10½ 3½	11 2½	10½ 1	9½ 0	8½ -1	7 -1	AM	28
28	AM	6 0	5 1	4½ 3	4½ 5½	4 8	3½ 9	3 11	2 11½	1 11½	0 10½	1 9½	1 8	PM	
	PM	½ 6	0 5	2 4	4 3½	6½ 3	9½ 2½	11 2	12 2	12½ 1	12 0	10½ -½	9 -1	AM	29
29	AM	7 -1	5 -½	3½ 1	2½ 3	2 6	1½ 8½	1½ 11	1 12½	1 13½	½ 13	-½ 12	-1 10	PM	
	PM	1½ 8	-1 5½	0 3½	2 2	4½ 1	7 1	10 1	12½ 1	14 1	14½ ½	13½ 0	11½ -1	AM	30
30	AM	9 1½	6½ -1½	4 -1	2 1	½ 3	0 6½	0 9½	½ 12½	½ 14½	½ 15½	0 15	-½ 13	PM	
	PM	-1½ 10½	-2 7½	-1½ 4	½ 2	2 0	5 -½	8 ½	12 0	14½ ½	16 1	16 ½	15 0	AM	31
31	AM	12 -1	8½ 2	5 -2	2 1½	0 ½	-1 4	1½ 7½	-½ 11	0 14½	1 16½	1 17½	½ 16	PM	
	PM	1 13½	1½ 10	2½ 6	-2 2½	-½ 0	2 -1½	6 -2	10 -1	14 0	17 1	18 1½	17½ 1	AM	

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		0 h.		1 h.		2 h		3 h		4 h.		5 h.		6 h.		7 h.		8 h.		9 h		10 h		11 h			
		12 h		13 h		14 h.		15 h		16 h		17 h		18 h.		19 h		20 h		21 h		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105 E	
75° W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	15 ½	0	12	-1	7 ½	-2	3 ½	-2 ½	0	1 ½	-1 ½	½	-2 ½	4	1 ½	8 ½	½	13	1	16 ½	2	19	2	19	PM	Dates 1
	PM	1	17	-½	13	-2	9	-3	4 ½	2 ½	1	-½	2	2 ½	-2 ½	7	-2	12	-½	16	1	19	2 ½	19 ½	3	AM	2
2	AM	18 ½	2	15	½	11	-1	6	-2 ½	2	-3	-1	-2	2 ½	1	-2 ½	5	1	10	1	15	3	18	3 ½	20	PM	
	PM	3	19 ½	2	17	0	12 ½	-2	7 ½	3	3	-2 ½	-1	-½	-2 ½	3 ½	-2 ½	8	-1	13	1	17 ½	3	20	4	AM	3
3	AM	20	4 ½	17 ½	3	13	1	8 ½	-1	3 ½	-3	0	-3	-2 ½	-1 ½	2 ½	2	-1 ½	7	1	12	3 ½	16 ½	5	19 ½	PM	
	PM	5 ½	20 ½	4 ½	19	2	15	0	10 ½	2 ½	5 ½	3	1	-2	-2	1	2 ½	5	1 ½	10 ½	½	15 ½	3	19	5 ½	AM	4
4	AM	20 ½	6 ½	19	6	16	4	11 ½	1 ½	6	-1	2	2 ½	1	-2 ½	-2 ½	-1	-2	3	0	8	3	13	5 ½	17	PM	
	PM	7	19 ½	7	19 ½	5 ½	17	3	13	0	8	-2	3	-2 ½	0	-1	-2	2	-2	6	0	11	2 ½	15 ½	5 ½	AM	5
5	AM	18 ½	7 ½	19	8 ½	17 ½	7 ½	14	5	9	2	4	-½	½	-2	1 ½	2	2	½	½	4	2 ½	9	5 ½	13 ½	PM	
	PM	8	17	9	18	8 ½	17 ½	6 ½	14 ½	4	10 ½	1	5 ½	-1	1 ½	-1 ½	-1	0	2	3	-1	7	2	11 ½	5	AM	6
6	AM	15	8	17	10	17	10	14 ½	8 ½	11	6	6	3	2	½	-½	-1	1 ½	½	-1	2	1 ½	5 ½	4 ½	9 ½	PM	
	PM	8	13	10	15	11	16	10	14	7 ½	11	4 ½	7	2	3	0	0	0	-1 ½	1	1	4	1	7 ½	4	AM	7
7	AM	11	7 ½	13 ½	10	14 ½	11 ½	13 ½	11	11	9 ½	7 ½	7	4	4	1	2	1	1	1	1	½	3	3	6	PM	
	PM	6 ½	9	9 ½	11 ½	11 ½	12 ½	12	12 ½	11	10 ½	8 ½	8	6	4	3 ½	1 ½	2	-½	1 ½	1	2 ½	0	4 ½	2 ½	AM	8
8	AM	7	5 ½	9 ½	8 ½	11	11	11	12	10	12	7 ½	10 ½	4 ½	8	2	5 ½	0	3 ½	-1	2 ½	½	2 ½	1 ½	3 ½	PM	
	PM	4 ½	5 ½	8	7 ½	10 ½	9	12	9 ½	12 ½	9	11 ½	7	10	5	7 ½	2	5	0	3 ½	-1	3	½	3 ½	1	AM	9
9	AM	4 ½	4	6	7	7	10	8	12	7 ½	13	6	12 ½	4	11	2	9	0	7	1	5	½	4	½	3 ½	PM	
	PM	3	4	5 ½	5	8 ½	5 ½	11	6	12 ½	6	13	5	12 ½	4	11	2	9	½	7	½	5	1	4	0	AM	10
10	AM	3 ½	2	4	4 ½	4	7 ½	4 ½	10	4 ½	12	4	13	3	13	2	12 ½	½	10 ½	½	8 ½	1	6 ½	½	5	PM	
	PM	1	4	3	3 ½	6	3	8 ½	3	10 ½	3	12 ½	3	13 ½	2 ½	13 ½	1 ½	12	½	10 ½	0	8 ½	½	6 ½	½	AM	11
11	AM	4 ½	½	3	2	2 ½	4 ½	2	7	2	10	2	12	1 ½	13 ½	1	14	½	13 ½	0	12	½	10	½	7 ½	PM	
	PM	0	5 ½	1	3 ½	3	2	5 ½	1 ½	8 ½	1	10 ½	1	13	1	14	1	14 ½	½	13 ½	0	12	0	9 ½	½	AM	12
12	AM	6 ½	0	4	½	2	2	1	4	0	7	0	10	0	12	½	14	½	15	½	14 ½	0	13	0	11	PM	
	PM	-½	8	0	5	1	2 ½	3	½	5	-½	8	1	11	-½	13 ½	0	15	½	15 ½	1	14 ½	½	12 ½	0	AM	13
13	AM	9 ½	0	6 ½	0	3	½	1	1 ½	1	4	1 ½	7	1	10	½	12 ½	0	15	1	16	1	15 ½	½	14	PM	
	PM	0	11	0	8	0	4	½	1	2	1	5	1 ½	8	1	11 ½	1	14	0	16	1	16	1 ½	15	1 ½	AM	14
	AM	12 ½	1	9	0	5 ½	0	2	0	0	1	2	3 ½	2	6 ½	-1	10	0	13 ½								

15	AM	14½	2	11	1	7½	0	3½	−½	½	0	−1½	1½	−2	4	−1	7½	½	11½	2	15	3	17	5½	17		
	PM	3	15	2	12½	½	8½	−½	5	−½	1	½	−1	3½	−1½	6	−1	10	½	14	2	16	4	17	4½	AM	16
16	AM	16	4	13½	3	10	1½	5½	0	2	−½	−½	0	−1½	2	−1	5	0	9	2	13	4	15½	5½	17	PM	
	PM	5½	16½	4	14	2½	10½	½	6½	½	3	−½	0	1	−1½	3½	−1	7½	½	11½	2½	15	5	17	6	AM	17
17	AM	17	6½	15	5½	12	4	8	1½	4	0	½	−½	−1	½	−1	3	0	6½	2½	10½	5	14	6½	16½	PM	
	PM	7	17	6½	15½	5	12½	2½	9	½	4½	½	1	0	−½	2	1	5	½	9	2½	13	5	15½	7	AM	18
18	AM	16½	8	15½	7½	12½	6	9	4	5	1½	1½	0	−½	0	−1	1½	½	4½	3	8	5½	12	7½	15	PM	
	PM	9	16½	8½	16	7	13½	4½	10	2	6	½	2½	0	0	1	−½	3½	0	7½	2½	11	5	14	8	AM	19
19	AM	16	9½	15½	9½	13½	8	10	6	6	3½	2½	1½	½	½	½	1	0	3	2	6	5	9½	8	13	PM	
	PM	9½	15	10	15	9	14	7	11	4½	7	2	3½	1	1	1	0	2½	0	5	2	8½	4½	12	7½	AM	20
20	AM	14	9½	14½	10½	13½	10	11	8½	7½	6	4	3½	1	1½	0	1	0	2	2	4	4½	7	7½	10½	PM	
	PM	10	13	11	14	11	13	9	11	7	8	4	4½	2	1½	1½	0	2	0	4	1	6½	3½	9½	7	AM	21
21	AM	12½	9½	13	11	12½	11½	10½	10	7½	8	4	5½	1½	3	0	2	0	2	1	3½	3½	6	6½	8½	PM	
	PM	9½	11	11	12	11½	12	10½	11	8½	8	6	5	4	2	2½	0	2½	0	3	½	5	3	7½	6	AM	22
22	AM	10	8½	11	11	11	12	10	11½	7½	10	5	7½	2	5	½	3½	−½	2½	½	3	2	4½	5	6½	PM	
	PM	8	8½	10½	10	11½	10½	11½	9½	10½	8	8½	5	6	2½	4	½	3	−½	3½	0	4	1½	6	4	AM	23
23	AM	7½	7	9	9½	9½	11½	8½	12	7	11	5	9½	2½	7½	½	5½	−½	4	0	3½	1½	4	3½	5	PM	
	PM	6½	6½	9	7½	11	8	11½	8	11½	6½	10	5	8	2½	6	½	5	½	4	−½	4	½	4½	2½	AM	24
24	AM	5½	6	6½	8½	7	10½	7	11½	6	11½	4	11	2½	9½	½	7½	−½	6	½	5	0	4½	2	4½	PM	
	PM	4½	5	7	6	9½	6	11	6	11½	5	11½	4	10	2	9	1	7	−½	5½	−1	5	0	4½	1½	AM	25
25	AM	4½	4	5	6½	5	9	5	10½	4	11½	3½	12	2	11	1	10	½	8½	1	7	−½	5½	½	5	PM	
	PM	2½	4½	5	4½	7½	4	9½	4	11	3½	12	3	12	2	11	1	9½	0	8	−1	6½	½	5½	0	AM	26
26	AM	4½	2	4	4	3½	6½	3	9	3	10½	2	12	1½	12½	1	12	0	11	−½	9½	−½	8	0	6	PM	
	PM	1	5	2½	4	5	3	7	2½	9½	2	11	1½	12½	1	13	1½	12	0	11	0	9	−½	7	0	AM	27
27	AM	5	½	3½	2	2½	4	2	6½	1½	9	1	11	1	12½	1	13½	½	13	0	12	−½	10½	0	8½	PM	
	PM	0	6	1	4	3	2½	5	1½	7½	1	10	½	12½	1	14	1	14	1	13½	1	12	½	9½	0	AM	28
28	AM	7	0	4½	½	2½	2	1	3½	½	6	0	9	½	12	1	14	1½	15	1½	15	1	14	½	11½	PM	
	PM	0	8½	0	5½	1	3	2	1	4½	0	7½	0	10½	½	13½	1	15½	2	16	2	15	2	13	1½	AM	29
29	AM																									PM	
	PM																									AM	30
30	AM																									PM	
	PM																									AM	
31	AM																									PM	
	PM																									AM	

Table 3

Month: March 1958

		0 h		1 h		2 h		3 h		4 h		5 h.		6 h		7 h.		8 h.		9 h		10 h		11 h			
		12 h		13 h		14 h.		15 h		16 h		17 h		18 h		19 h		20 h.		21 h		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105° E	
75° W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	10	½	7	0	3½	0	1	1	0	3	−½	6	0	9	1	12½	2	15	3	16½	3	16½	2½	15	PM	Dates 1
	PM	1	12	0	8	½	4½	0	1½	1½	0	4	1	8	0	11½	1	15	2½	17	4	17½	4	16	3½	AM	2
2	AM	13½	2½	9½	1	5½	0	2	−½	0	0	1	3	−½	6	1	10	3	14	4½	17	5	18	5	17	PM	
	PM	3½	15	2	11	0	7	−1	3	−1	0	1	−1	4	½	8	1	12½	3	16	5	18	6½	18	6½	AM	3
3	AM	16½	5	13	3	9	1	4½	−½	1	−1½	−1	0	−1	2½	0	6½	2½	11	5	15	7	18	8	18½	PM	
	PM	7	17	5	14	2	10	0	5	−1½	1½	−1½	−1	½	−1	4	0	9	3	13	5½	16½	8	18½	9	AM	4
4	AM	18	8½	15½	7	11	4	6½	1	2½	−1	½	−2	−1	½	½	2½	2	7	5½	11½	8½	15½	10	18	PM	
	PM	10½	18	8½	16	6	12	2½	7½	−½	3	−2	0	1½	1	1	−½	4½	2	9½	5	14	8½	17	11	AM	5
5	AM	18	11½	16½	10	13½	7	9	4	4½	½	1	1½	−1	−2	−1	0	1	3½	4½	8	8	12½	11	16	PM	
	PM	13	17	12	16	10	13	6½	9	2½	5	½	1	−2	1	1½	−1	1	1	5	4½	9½	8½	13½	12	AM	6
6	AM	16	13½	16	13½	14	11½	10½	8	6½	4	2	½	0	1½	−1	−1½	0	½	3	4	7	8	11	12	PM	
	PM	13½	14½	14½	15	13½	13½	10½	10½	7	6½	3	3	0	0	1½	−1	−1	0	2	3	5	7	9	11	AM	7
7	AM	12½	14	14	15	13	14½	10½	12	7	8½	3	4½	0	1	−1	−1	½	1	2	1	6	4	10	7½	PM	
	PM	13½	10½	15½	12	15½	12	13½	10	10	7	6	3½	2½	1	0	−1	−½	−1	½	1	3	4½	6	8½	AM	8
8	AM	8½	13	10½	15	11	16	9½	14½	7	12	4	8	1	4½	½	2	1	0	½	0	3½	2	7½	4	PM	
	PM	11½	7	14½	9	16½	9½	15½	8½	13½	7	10	4	6½	1½	3½	−½	1½	−1	½	0	1	3	3	6½	AM	9
9	AM	5	10½	7	13½	8	15½	7½	16	6	14½	4	12	1½	8½	0	5½	1	3	½	1½	1½	1	5	2	PM	
	PM	8½	4	12	5½	14½	6	15½	6½	15	5½	13	4	10	2	7	0	4½	−1	2½	½	1½	1	2	4	AM	10
10	AM	3	7	4	10½	4½	13	5	15	4½	15	3	14	1½	12	0	9	½	6	½	4	½	2½	3	2	PM	
	PM	6	2	9	3	12	3½	14	4	14½	3½	14	3	12½	1½	10	½	7½	−½	5½	½	3½	½	2½	2	AM	11
11	AM	2	5	2	8	2½	10½	2½	13	2½	14	2	14½	1½	13½	½	12	0	9½	0	7	0	5	1½	3	PM	
	PM	3½	2	6	2	9	1½	11	1½	13	2	14	1½	14	1	13	1	11	½	9	0	6½	½	4½	1½	AM	12
12	AM	3	3	1½	5	1	7½	1	10	1	12	1	13	1½	14	1	13½	½	12	½	10	½	8	1	5½	PM	
	PM	2	3½	3½	2	6	1	8	½	10	0	12	½	13	1	13½	1	13	1	11½	1	9½	1	7	1½	AM	13
13	AM	4½	2	2½	3	1	4½	0	6½	½	8½	0	10½	½	12½	1	13½	1½	13½	1½	12½	2	11	2	8½	PM	
	PM	2	6	2½	3½	3½	1	5	0	7	[illegible]	9½	0	11½	½	13	1	14	2	13½	2½	12	2½	10	2½	AM	14
14	AM	7	2½	4	2½	2	3	0	4	½	6	½	8	0	10	1½	12	2½	13½	3	14					PM	

15	AM	9½	3½	6½	3	3½	2	1	2½	0	3½	−½	5	0	8	1½	10½	3	12½	4½	14	[illegible]	[illegible]	[illegible]	[illegible]		
	PM	4½	10½	3½	7½	2	4	2	1½	2½	0	4	−½	6	0	9	2	12	4	14	5½	14½	6	13½	6½	AM	16
16	AM	11½	5½	8½	4	5	3	2	2	½	2	−½	3	½	5	2	8	4	11	6	13	7	14½	7½	14	PM	
	PM	6½	12½	5	9½	3	6	2	3	1½	½	2	0	4	½	7	2	10	4	13	6½	14½	8	14½	8½	AM	17
17	AM	13	8	10	6	7	4	3½	2	1	1	0	1½	½	3	2	6	4	9	7	12	8½	14	9½	14½	PM	
	PM	9	13½	7½	11	5	7½	3	4	1	1½	1	0	2½	½	4½	2	8	4½	11	7	13	9	14½	10½	AM	18
18	AM	14	10	12	8½	8½	7	5	3½	2	1½	½	1	½	1½	1½	3½	4	7	7	10	9½	12½	11	14	PM	
	PM	11	14	10	12	7½	9	4½	5½	2	2½	1	½	1	0	2½	1½	5½	4	9	7	11½	10	13½	12	AM	19
19	AM	13½	12	12	11	9	8½	6	5½	3	3	½	1	½	½	1½	2	4	4½	7	7½	10	10½	12½	13	PM	
	PM	13	13½	12	12½	9½	10	6½	6½	3½	3	1	1	½	0	1½	1	4	3	7	6½	10	9½	12	12	AM	20
20	AM	13	13½	12	13	10	10½	7	7½	3½	4½	1	2	0	½	1	1	3	3	6	5½	9½	9	12½	11	PM	
	PM	14	12½	13½	12	12	10	8½	7	5½	4	2½	1½	1	0	1	½	2	2½	4½	5½	7½	9	10	12	AM	21
21	AM	11½	14	11½	14	10	12½	7½	10	4	6½	1½	3½	0	1½	0	½	2	1½	5	4	8½	6½	11½	9	PM	
	PM	14	10½	14½	11	13½	9½	11	7	7½	4½	4½	2	2	0	1	0	1	1½	3	4	5	7½	8	11	AM	22
22	AM	9½	13½	10	14½	9	14	7	12	4	9	1½	5½	0	2½	0	1	1	1	4	2	7½	4	11	6½	PM	
	PM	13½	8½	14½	9	14	8½	12½	7	9	4½	6	2	3	0	1½	−½	1	½	2	2½	3½	6	6	9½	AM	23
23	AM	7½	13	8½	14½	8	14½	6½	13	4	10½	1½	7	0	4½	−½	2	0	1	2	1½	5½	3	9	5	PM	
	PM	12	6½	14	7	14½	7	13½	6	11½	4	8½	2	5½	0	3	−½	2	0	1½	1½	2½	4½	4	8	AM	24
24	AM	5½	11½	6½	13½	6½	14½	5½	14	4	12	2	9½	0	6½	−1	4	−½	2½	1	1½	3½	2	7	3	PM	
	PM	10	4½	12½	5	14	5½	14	4½	13	3½	10½	1½	8	0	5	−1	3	−1	2	½	2	3	2½	6	AM	25
25	AM	3½	9	4½	12	4½	13½	4	14	3	13½	1½	11½	0	9	−1	6½	−1	4	0	3	2	2	5	2½	PM	
	PM	8	3	11	3½	13	4	14	3½	13½	2½	12½	1½	10	½	7½	−½	5½	−1	3½	½	2½	1	2½	4	AM	26
26	AM	2½	7	3	10	3	12	3	13½	2	13½	1½	13	0	11	½	9	−1	6½	−½	5	1	3½	3	2½	PM	
	PM	5½	2½	8½	2½	11½	2½	12½	2	13½	2	13	1½	12	½	10½	0	8	½	6	0	4½	½	3	2½	AM	27
27	AM	2	5	2	7½	2	10	½	12	1½	13	1	13½	1	13	½	11½	0	10	0	7½	½	5½	1½	4	PM	
	PM	3½	2½	5½	2	8	1½	10½	1½	12	1½	13	1	13½	1	12½	1	11	½	9	½	7	1	5	1½	AM	28
28	AM	3	3	2	5	1	7	1	9	1	11	1½	13	1½	13½	1½	13½	1½	12½	1	10½	1	8½	1½	6	PM	
	PM	2½	4	3½	2	5½	1	8	½	10	1	12	1½	13½	2	14	2½	13½	2½	12	2½	9	2	7	2	AM	29
29	AM	4½	2	2½	3	1	4	½	6	½	8½	1	11	2	13	3	14	3½	14	3½	13	3	11	2½	8½	PM	
	PM	2	5½	2½	3	3	1	4½	½	6½	½	9	1	12	2½	14	3½	14½	4½	14	5	12½	4½	10	3½	AM	30
30	AM	7	3	4	2	2	2	½	3	0	5	1	8	2½	10½	4	13	5½	14½	6	15	6	14	5	11½	PM	
	PM	3½	8½	2½	5	1½	2	2	½	3	0	5½	½	9	2½	12	4½	14	6½	15	7½	15	7½	13	6½	AM	31
31	AM	10	5	6	3	3	2	½	1	0	2	½	4	2	7	4½	10½	7	13	8½	15	9	15½	8½	14	PM	
	PM	6½	11	4	7½	2	4	½	1	½	0	2	0	5	2	8½	4½	12	7	14½	10	15	11	14½	10½	AM	

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		0 h		1 h		2 h		3 h.		4 h.		5 h.		6 h		7 h		8 h		9 h		10 h		11 h			
		12 h		13 h		14 h.		15 h		16 h		17 h.		18 h		19 h		20 h		21 h		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105 E	
75 W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	12	8½	8½	5½	5	3	2	½	0	0	0	1	1	3	4	6½	7	10½	10	13½	12	15	12	15	PM	Dates
	PM	10½	12½	8	9½	4	5½	1½	2	−½	0	−½	½	1	1	4	4	8	7½	11½	11	14	13	14½	14	AM	2
2	AM	13½	12½	10½	9½	7	6	3	2½	½	0	−1	−1	0	0	3	2½	6	6½	10	10	13	13	15	14	PM	
	PM	14½	13½	12	11	8	7	4	3½	½	½	1½	−1	1½	0	½	2½	4	6	7½	10½	11	14	13	16	AM	3
3	AM	13	16	11	14	8	10	4	6	1	2	−1	1	−1	−2	1	1	5	2	9½	6	14	9½	16½	12	PM	
	PM	17	12½	15½	11	12	8	7½	5	3	1½	½	−1	−2	−1	−1½	½	½	4	4	8½	7½	13	10	16½	AM	4
4	AM	11½	18	11	17	8½	14	5	9½	2	5	−½	1	1½	−1½	0	−2	3	−1	7	2	12	5½	16	8½	PM	
	PM	18	10	18	10	16	8	12	5½	7	2	2½	0	½	1½	−2	−1	−1½	2	½	6	3	11	6½	15	AM	5
5	AM	8½	18	9	19	8	17	5½	14	3	9	0	4½	−1½	½	−1½	1½	1	2	4½	−½	9	1½	14	4½	PM	
	PM	16	7	19	8	18	7	15½	5½	11	3	6½	0	2½	−1½	½	1½	−2	0	1½	3½	½	8	3	12½	AM	6
6	AM	5½	16	6½	18½	6½	18½	5	16½	3	13	0	8½	−1½	4	−1½	1	0	−1	2½	−1½	7	−½	11	1½	PM	
	PM	15½	3½	18	5	18½	5½	17	4½	14	3	10	1	6	−1	2	1½	0	−1	−1	1	1	4½	½	9	AM	7
7	AM	2½	13½	4	16½	4½	18	4	17½	2½	15	1	11½	½	7½	−1½	4	−1	1	1	½	4	1	8	0	PM	
	PM	12	1½	15	2½	17	3	17	3	15½	2½	13	1	9½	0	6	−1	2½	−1	½	½	½	3	−½	6½	AM	8
8	AM	½	10	1½	13½	2	15½	2½	16½	2	16	1	14	0	11	½	7½	−½	4	0	2	2	½	5	0	PM	
	PM	8½	0	11½	1	14	1½	15½	2	15½	1½	14	1	12	½	9	0	6	0	3	½	1½	2	0	4	AM	9
9	AM	0	7	½	10	1	12½	1	14	1½	15	1	14½	1	12½	½	10	½	7½	1	5	2	2½	3½	1	PM	
	PM	6	0	8½	0	11	0	13	½	14	1	14	1	13	1	11	1	8½	1	6	1	3½	2	2	3	AM	10
10	AM	½	5	0	7½	0	9½	0	11½	½	12½	1	13½	1½	13	2	12	2	10	2	7½	2½	5	3	3	PM	
	PM	4½	1	6	½	8	0	10	0	11	½	12½	1	13	2	12	2½	10½	3	9	3	6½	3	4	3½	AM	11
11	AM	2	4½	1	5½	0	7	0	8½	0	10	1	11	2	12	3	12	3½	11	3½	9½	4	7½	4	5½	PM	
	PM	4	3	4½	1	5½	0	7	0	8½	½	10	1	11	2½	12	3½	11½	4½	10½	5	8½	5	6½	5	AM	12
12	AM	4	4½	2	4½	½	5	0	6	0	7	1	9	3	10	4	11½	5½	12	6	11	6	9½	5½	7½	PM	
	PM	5	5	4½	3	4½	1	5	0	6	½	7½	1½	9½	3	11	5	11½	6	11½	7	10	7	8	6½	AM	13
13	AM	6	6	3	5	1	4	½	4	½	5	1	6½	3	8	5	10	7	11	8	11½	8½	10½	8	9	PM	
	PM	6½	6½	5	4	4	2	3½	½	4	½	5	1	7	3	9	5	10½	7½	11½	9	11	9½	9½	9	AM	14
14	AM	7½	8	5	6	2½	4½	1	3½	½	3½	1	4	3	6	5½	8	8	10	10	11	10½	11			PM	

15	PM	11	9	9	7	6	4	4	1½	2	½	2	½	3	2	5	5	7	8	9½	11	10½	13	10½	13½	AM	16
16	AM	9	12½	7	10	4	7	2	4½	½	2½	½	1½	2	2	4½	4	8	6	11	8½	13½	10	14½	10½	PM	
	PM	13½	9½	11½	7½	8	5	5	2	2½	½	1	0	1½	1½	3	4	5	7½	7½	11	9	13½	10	15	AM	17
17	AM	9½	14½	7½	12½	5	9½	2½	6	½	3	0	1	1	1	3½	2	7	4	10½	6	13½	8	15½	9½	PM	
	PM	15½	9	13½	7½	10½	5	7	2½	3½	½	1	0	½	½	1	3	3	6	5	10	7	13	8½	15½	AM	18
18	AM	8½	16	7	14½	5	12	2½	8	½	4½	½	1½	0	0	2½	½	6	2	10	4	13½	6	16	8	PM	
	PM	16½	8½	15	7½	12	5½	8½	3	5	½	2	−½	0	−½	0	1½	1	5	3	8½	5	12	7	15	AM	19
19	AM	7½	16½	7	16	5	13½	3	10	½	6	−1	2½	−½	½	1	−½	4	0	8	2	12	4	15	6	PM	
	PM	17	7	16½	6½	14	5	11	3	7	½	3	−1	½	−1	−½	0	½	3	1	7	3	11	5	14½	AM	20
20	AM	6	16½	6	17	5	15	3	12	½	8	−1	4½	−1½	1½	0	0	2½	½	6	½	10	2	14	4	PM	
	PM	16	5	17	5	16	4½	13	2½	9½	½	5½	1	2	−1½	0	−1	½	1½	0	5	1	9	3	13	AM	21
21	AM	4	15½	4½	17	4	16½	2	14	½	11	−1	7	−1½	3	−1	½	1	−½	4½	−½	8½	½	12	2	PM	
	PM	15½	3	17	4	16½	3½	14½	2	11½	½	7½	−1	4	−2	1½	−1½	0	0	−½	3	0	6½	1	10½	AM	22
22	AM	2½	14½	3	16½	3	17	2	15½	½	12½	1	9	−2	5½	−1½	2½	0	½	2½	−½	6	0	10	½	PM	
	PM	13½	2	15½	2½	16½	2½	16	2	13½	½	10½	−1	7	−1½	3½	1½	1½	−½	0	2	0	5	0	9	AM	23
23	AM	1	12½	2	15	2	16	1½	16	1	14	−½	11½	−1½	8	−1½	5	−1	2½	1	½	4	0	7	0	PM	
	PM	11	½	13½	1	15½	1½	16	1½	15	1	12½	0	9½	−1	6½	−1	3½	−1	1½	½	½	3	0	6	AM	24
24	AM	½	9½	1	12½	1½	14½	1½	15½	1	15	½	13½	½	11	−1	8	½	5	½	2½	2½	1	5	0	PM	
	PM	8	0	11	½	13½	1	14½	1	15	1	14	1	12	½	9½	0	6½	0	4	½	2	2	½	4	AM	25
25	AM	0	7	½	9½	½	12	1	14	1½	14½	1½	14	1	12½	1	10½	½	8	1	5	2	3	3½	1	PM	
	PM	5½	½	8	0	10½	½	12½	1	13½	1½	14	2	13½	2	11½	2	9½	2	7	2	4	2½	2	3	AM	26
26	AM	1	5	0	6½	½	9	1	11	1½	12½	2½	13½	3	13½	3½	12½	3	10½	3	8	3	5½	3	3	PM	
	PM	4	1	5	½	6	0	9	1	11	1½	12½	3	13	4	13	4½	11½	4½	9½	4½	7	4	4	3½	AM	27
27	AM	2	4	½	4½	0	6	½	7½	1½	9½	3	11	4½	12½	5½	13	6	12	6	10½	5	8	4½	5	PM	
	PM	4	3	4	1	4½	0	6	½	7½	1½	9½	3	11½	5	12½	6½	12½	7½	11	7½	9	7	6½	5½	AM	28
28	AM	3½	4½	1½	3½	0	3½	0	4½	1	6	3	8	5	10	7	11½	9	12	9½	11½	9	10	7½	7	PM	
	PM	5½	4	4	2	3	0	3	0	4	½	6	3	9	5½	10	8	11½	10	12	11	10½	10½	8½	9	AM	29
29	AM	5½	7	2½	4½	½	3	−½	2	0	2½	2	4	4½	6½	8	9	10½	10½	12	11½	12½	11	11	9	PM	
	PM	9	6	6	3	3½	½	1½	½	1	0	2	1½	4	5	6½	8	9	11½	10½	13½	11	14	9½	13	AM	30
30	AM	6½	11	3½	7½	1	4	−1	1½	−1	½	1	1	4	2½	8	5	12	7½	14½	9½	15½	10½	15	9½	PM	
	PM	12½	7½	9	4½	5	1½	2	−½	0	1	−½	0	1	3	3	7	6	11	8½	14½	9½	17	9	17	AM	
31	AM																									PM	
	PM																									AM	

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		0 h		1 h		2 h		3 h		4 h		5 h		6 h		7 h		8 h		9 h		10 h		11 h			
		12 h		13 h		14 h		15 h		16 h		17 h		18 h		19 h		20 h.		21 h		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105	E
75	W	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	7½	15	4½	11	2	7	−½	3	−1½	0	½	−1½	2	−1	6	1	10½	4	15	6½	17½	8½	18	9	PM	Dates 1
	PM	16½	7½	13	15	9	2	4	0	½	−2	−1½	−1½	−2	1	½	5	2	10	5	14½	7	17½	8	19	AM	2
2	AM	7	18½	5½	15½	2½	11	0	6	2	2	−2	1	0	−2½	3½	−2	8	0	13	3	17	5½	19½	7	PM	
	PM	19½	7	17	5	13	3	8	0	3	−2	−½	2½	−2½	−1	−3	2	−1½	7	1	12	4	16½	5½	19½	AM	3
3	AM	6	20½	5	19	3	15½	½	10½	−2	5	2½	½	−2	−2	1	−3	5	2½	10	½	15	2	19	4	PM	
	PM	20½	5	20	5	17	3	12	1	7	−1½	2	−3	−1½	2½	−3	0	−3	3½	−2	8½	½	13½	3	18	AM	4
4	AM	4	20½	4½	20½	3	18	1	14	−1	9	3	3½	−3	−½	1	−3	2	−3½	7	−2½	12	½	16	1½	PM	
	PM	19½	3	20½	3½	19	3	15½	1	10½	−1	5½	2½	1	−3	−2	1½	3½	1½	3	6	2	10½	0	15	AM	5
5	AM	2	18½	3	20	2½	19½	1½	16½	−½	12	−2	7	2½	2½	−2	1	0	3	4	−3	8	2	13	−½	PM	
	PM	17	1	19	2	19½	2	17½	1½	14	0	9	−1½	4½	−2½	1	−2	−2	0	−3	3	2½	7	1½	11½	AM	6
6	AM	0	15½	1	18	2	19	1½	17½	0	15	1	10½	2	6	−2	2	½	−1	2	2½	6	−2½	10	−2	PM	
	PM	14	−½	16½	½	18	1½	17½	1½	15	½	11½	−½	7½	1	3½	1½	½	−½	1½	1½	2½	4½	−2	8	AM	7
7	AM	−1	12	0	15	1	17	1	17	1	15½	0	12½	−½	9	−1	5	0	2	1	−½	4	−2	7	−2	PM	
	PM	10	1½	13	½	15	½	16	1	15	1	13	1	10	½	6½	0	3	½	½	1½	−1	3½	−1½	6	AM	8
8	AM	−1½	9	−1	12	½	14	1	15	1½	14½	1½	13	1	11	1	8	1	4½	2	2	3	0	5	−1	PM	
	PM	7½	−1½	10	−1	12	0	13½	1	14	1½	13	2	11	2	8½	2	6	2	3	2½	1	3½	½	5	AM	9
9	AM	−1	6½	−½	9	0	11	1	12	2	13	2½	12½	3	11½	3	9½	3	7	3½	4	4	2	5	½	PM	
	PM	6	−½	8	−½	9½	0	11	1	12	2	12	3	11	3½	9½	4	7½	4½	5	4½	3	4½	7	5	AM	10
10	AM	0	6	−½	7	0	8	1	9½	2	10½	3½	11	4½	11	5	10	5½	8	5½	6	5½	4	5½	2	PM	
	PM	6	½	6½	0	7½	0	8½	½	9½	2	10	3½	10½	5	10	6	8½	6½	7	7	5	7½	2½	6	AM	11
11	AM	1	6	0	6	0	6½	½	7	2	8	3½	9	5½	9½	7	9½	8	9	8	7½	7½	5½	7	3½	PM	
	PM	6½	1½	6	½	6	0	6½	½	7	1½	8	3½	9	5½	9½	7½	9	9	8	9	6	9	4	8	AM	12
12	AM	2	7	1	6	0	5½	½	5½	1½	6	3½	7	6	8	8	8½	9½	9	10½	8	10	7	9	5	PM	
	PM	8	3	6½	1	5	0	5	0	5	1	6	3	7	5½	8	8	8½	10	8	11	7	11½	5	10½	AM	13
13	AM	3	9	1½	7	0	5½	0	4½	1	4	3	5	5½	6	8	7	10½	8	12	8	12½	7	11½	5½	PM	
	PM	10	3½	7½	2	5½	½	4	0	3½	½	3½	2½	4½	5	6	8	7	11	7½	13	7	13½	6	12½	AM	14
	AM	4	11	2	8½	½	6	½	4																		

15	PM	14 5	11½ 3	8 1	4½ −½	2 −1	½ 0	½ 2½	1½ 6	3 10	5 13½	5½ 15½	5½ 16	AM	16
16	AM	4½ 15	3 12½	1 9	−1 5½	−1½ 2	−½ ½	2 0	5 ½	9½ 2	13 4	16 5	17 5	PM	
	PM	16 4½	13½ 3	10 1	6 −1	3 −1½	½ −1	−½ 1	0 4½	1 9	3 13	4 16	4½ 17	AM	17
17	AM	4 17	3 15	1 11	−1 7	−2 3	1½ ½	0 −1	3½ 1	7½ 0	12 1½	15½ 3	17 4	PM	
	PM	17½ 4	16 3	12½ 1	8 −1	4 −2	1 −2	−1 −½	−1½ 2½	−1 7	½ 11	2 15	3 17½	AM	18
18	AM	3½ 18	2½ 16½	½ 14	1 9½	2 5	−2 1½	−1 −1	2 2	6 1½	10½ −½	15 1	17½ 2½	PM	
	PM	18 3	17 2½	14 1	10 −1	6 −2	2 2½	−1 −1½	−2 ½	−2 4½	−1 9	½ 13	2 16½	AM	19
19	AM	2½ 18½	2 18	1 15½	−1 12	2 8	−3 3	−2 0	0 −2	4 −2½	8½ −2	13 ½	16 1	PM	
	PM	18 1½	18½ 2	16 1	13 −½	8½ −2	4 −3	½ −2½	−2 −1	−2½ 2½	2 7	−1 11	½ 15	AM	20
20	AM	1½ 18	1½ 18½	1 17½	½ 14½	2 10½	3 6	2½ 2	−1 −1	2 2½	6 −2½	10 1½	14½ −½	PM	
	PM	17 ½	18½ 1	18 1	15 0	11½ −1½	7 2½	3 −3	0 −2	−2 ½	2½ 4	−2 8½	−1 13	AM	21
21	AM	½ 16	1 18	1 18	0 16½	1 13	−2½ 9	−2½ 4½	2 1	½ 1½	3½ −2½	8 −2½	12 1½	PM	
	PM	15½ 0	17½ ½	18 1	16½ ½	13½ ½	9½ −1½	5½ −2½	2 −2	½ −½	2 2	2 5½	−1½ 10	AM	22
22	AM	−½ 14	½ 16½	1 17½	1 17	0 14½	−1 11	1½ 7	−1½ 3½	½ ½	2 −1	5 2	9 −1½	PM	
	PM	12½ −½	15½ ½	17 1	17 1	15 ½	12 0	8½ −1	5 −1	2 −½	−½ 1½	−1½ 4	−1½ 7½	AM	23
23	AM	1 11	0 14	1 16	1½ 16½	1½ 15½	−1 13	0 10	0 6½	0 3	1½ ½	3 −1	6 −1½	PM	
	PM	9½ 1	12½ 0	14½ 1	15½ 2	15 2	13½ 2	11 1½	7½ 1	4 1	1½ 1½	0 3	−1 5	AM	24
24	AM	1 8	0 11	1 13	2 14½	3 15	3 14	2½ 12	2 9	2 5½	2 3	3 ½	4½ 1	PM	
	PM	7 1	9 −½	11½ 1	13 2	14 3	13½ 4	12 4	9½ 3½	6½ 3	3½ 3	1 3½	0 4	AM	25
25	AM	1 5½	½ 7½	1 10	2 11½	3½ 12½	5 13	5½ 12	5½ 10	5 7½	4½ 4½	4 2	4 ½	PM	
	PM	5 ½	6 ½	8 ½	10 2	11 4	12 5½	11½ 6½	10½ 7	8 6½	5½ 6	3 5	1 4½	AM	26
26	AM	−½ 4½	½ 5½	0 6½	1½ 8	3½ 9½	6 10½	7½ 11	8½ 10	8½ 8½	8 6½	7 4	5½ 1½	PM	
	PM	5 0	4½ 1	5 ½	6 1	7½ 3½	9 6	9½ 8	9½ 9½	9 10½	7 9½	4½ 8½	2 7	AM	27
27	AM	0 5½	−1 4½	1 4	½ 4½	2½ 5½	5½ 7	8 8	10½ 9	12 8½	11½ 7	10½ 5	8½ 3	PM	
	PM	6½ ½	4½ −½	3½ −1	3 0	4 2	5 5	6½ 8	7½ 11	8 13	7 13½	5½ 12½	3 10½	AM	28
28	AM	1 8	½ 5	−1½ 3	−1 2	1 2	4 3	7½ 4½	11 6	13½ 7	15 6½	14½ 5½	12½ 3½	PM	
	PM	10 1½	6½ −½	3½ −1½	2 −1½	1 0	1½ 3½	2½ 7	4 11	5½ 14	6 16	5½ 16	4 14½	AM	29
29	AM	2 11½	0 8	−2 4½	−2 1½	1 0	2 0	5½ 1	10 2½	14 4	16½ 5	17½ 5	16½ 4	PM	
	PM	14 2	10 0	6 2	2½ 2½	0 1½	−1 1	−½ 5	1 9½	2½ 13½	4 17	4½ 18½	4 18	AM	30
30	AM	2 15½	0 12	−2 7½	−3 3	2½ 0	0 −2	3½ −2	8 1	13 1	17 2½	19 3½	19 3½	PM	
	PM	17 2½	14 ½	9 −1½	4 −3	½ 3	−2 1½	−3 2	−2 6½	−½ 11½	1½ 16	3 19	3 20	AM	31
31	AM	2 19	½ 15½	−1½ 11	3 6	−3½ 1½	−2½ −2	½ −3½	5 −3	10 −2	15 0	18½ 1½	20½ 2½	PM	
	PM	20 2	17 1	13 1	8 3	3 −4	−1 −3	3½ −1	−4 3	−3 8½	1½ 14	½ 18	2 20½	AM	

Table 3

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		0 h.		1 h		2 h.		3 h		4 h.		5 h		6 h.		7 h.		8 h.		9 h.		10 h		11 h			
		12 h		13 h		14 h		15 h.		16 h		17 h		18 h		19 h.		20 h.		21 h		22 h.		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105° E	
75° W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	2	20½	1	19	−1	15	−2½	10	−4	4	−4	0	−2	−3	1½	4	6	−4	11	2½	16	−½	19½	1	PM	Dates 1
	PM	21	1½	20	1	16½	½	11½	−2	6	3½	1	−4	2½	−2½	−4	0	−4½	5	−3½	10	1½	15	0	18½	AM	2
2	AM	1	20½	1	20	0	17½	−2	13	−3½	8	−4	3	−3	1	−½	−4	4	−4½	9	−4	14	−2	18	−½	PM	
	PM	20	½	20	1	18	½	14	−1	9	−2½	3½	−3½	−½	−3½	−3	1½	−4½	2	−4	6½	−3	11	−1	15½	AM	3
3	AM	½	19	1	20	½	18½	½	15	−2	10½	−3	5½	−3	1	−1½	−2	1½	−4	5½	−4	10	3	14½	−1½	PM	
	PM	18	0	19	1	18½	1	16	0	12	−1	7	−2	2½	2½	−1	−2	−3	½	−4	4½	−3½	8½	−2	13	AM	4
4	AM	½	16½	1	18½	1½	18½	1	16½	0	13	−1½	8½	−2	4	−1½	0	0	2	3	−3½	7	3	11	2	PM	
	PM	14½	−½	17	1	18	1½	16½	1½	13½	½	9½	−½	5½	−1	1½	−1	−1½	0	−3	2½	3	6	−2	9½	AM	5
5	AM	−1	13	½	15½	1½	17	2	16	1½	14	½	10½	0	6½	0	3	½	0	2½	−2	5	−2½	8½	2	PM	
	PM	12	−1	14	½	15½	1½	15½	2½	14	2½	11	2	7	1	4	1	1	1	1½	2½	−2	4½	2	7	AM	6
6	AM	1	10½	½	13	2	14½	2½	15	3	13½	3	11	2	8	2	5	2	2	2½	½	4	1½	6½	1½	PM	
	PM	9	−1	11½	½	13	2	14	3	13	3½	11½	4	9	3½	6	3	3	3	½	3½	−1	4½	1½	6	AM	7
7	AM	1	8	0	10	1½	12	3	13	4	12½	4½	11½	4½	9	4	6½	4	3½	4	1	4½	−½	5½	−1	PM	
	PM	7	−1	9	0	10½	1½	11½	3	12	4½	11	5½	9½	6	7	5½	4½	5½	2	5	0	5½	−1	6	AM	8
8	AM	−1	7	0	8	1	9½	3	10½	4½	11	5½	10½	6½	9	6½	7½	6½	5	6	3	6	1	6	−½	PM	
	PM	6½	−½	7	0	8	1	9	3	9½	4½	9½	6	9	7	7½	8	5½	8	3½	7½	1½	7	0	6½	AM	9
9	AM	½	6½	½	7	½	7½	2½	8	4	8½	6	9	7½	8½	8½	7½	9	5½	8½	4	8	2	7	½	PM	
	PM	6½	−½	6½	−½	6½	½	7	2	7½	4	7½	6	7½	8	7	9½	6	10	4	9½	2½	9	1	8	AM	10
10	AM	0	7	−½	6½	0	6	1½	6	3	6½	5½	7	8	7	10	6½	11	6	11	4½	10	2½	9	1	PM	
	PM	7½	0	6½	½	5½	0	5	1	5	3	5½	5½	6	8	6	10	5½	11½	4½	12	3	11	1½	10	AM	11
11	AM	0	8½	−1	6½	½	5½	½	4½	2½	4	5	4½	8	5	10½	5½	12	5	13	4½	12½	3	11	1½	PM	
	PM	9	0	7	−1	5	−1	4	0	3½	2	3½	4½	4	7½	4½	10	4½	12½	4	13½	3	13½	2	12	AM	12
12	AM	0	10	−1	7½	1½	5	−1	3½	1	2½	3½	2½	7½	3	10	3½	12½	4	14	4	14½	3	13	2	PM	
	PM	11	½	8	−1	5½	1½	3	1	2	0	1½	3	2	6½	2½	10	3	13	3½	14½	3	15	2	14	AM	13
13	AM	½	12	−1	9	2	6	−2	3½	−½	1½	2	½	5	½	9	1½	12	2	15	3	16	2½	15½	2	PM	
	PM	13½	½	10½	1	7	2	4	−2	1	1	0	1	0	4½	½	8½	1	12	2	15	2½	16½	2	16	AM	14
	AM	½	14½	1	11½	2	8																				

15	PM	17½ 1	15 -½	11 -2	7 -3	3 -3½	0 -2½	-2 0	-3 4	-2 9	-1 13	0 16½	1 18½	AM	16
16	AM	1 18½	0 16½	-1½ 12½	-3 8	-3½ 3½	-3 0	-1 -2	2½ -3	7 -3	11½ -1½	15½ -½	18½ ½	PM	
	PM	19 1	17½ 0	14½ -½	10 -3	5 -3½	1 -3½	-2 -1½	-3½ 1½	-3½ 6	-2½ 11	-1 15	0 18	AM	17
17	AM	½ 19½	0 18½	1 15½	-2½ 11½	-3½ 7	-3½ 2	-2 -1½	½ -3	4½ -3½	9½ -3	14 -1½	17½ 0	PM	
	PM	19½ ½	19 ½	16½ -½	13 -2	8 -3	3 -3½	-½ -2½	-3 -½	-3½ 3½	-3 8	-2 12½	-½ 17	AM	18
18	AM	½ 19	1 19½	0 17½	-1 14	-2½ 10	-3½ 5	-3 ½	-1 -2	2 -3½	6½ -3	11 -2	15½ -½	PM	
	PM	18½ ½	19½ 1	18 ½	15½ -½	11 -2	6 -3	2 -3	-1½ -1½	3 1	-3½ 5½	-2½ 10	-1 14½	AM	19
19	AM	½ 17½	1½ 19	1½ 19	½ 16	-1 12½	-2 8	-2½ 3	-2 0	½ -2½	4 -3	8 -2½	12½ -1	PM	
	PM	16 ½	18½ 1½	19 2	17 1½	14 0	9 -1	5 -2	1 -1½	-1½ 0	-3 3	-2½ 7	-1½ 11	AM	20
20	AM	½ 15	2 17½	2½ 18½	2 17	1 14½	0 10½	-1 6	-1 2	0 -1	2½ -2	6 -2½	10 1½	PM	
	PM	14 0	16 2	17½ 3	17 3	14½ 2½	11 1½	6½ ½	3 0	0 0	-2 1½	-2 4	-1½ 8	AM	21
21	AM	0 11½	2 14½	3 16½	4 16½	3½ 15	2½ 12	1½ 8½	1 4½	1 1	2 -1	4 -2	7 -1½	PM	
	PM	10 0	13 1½	15 3½	15½ 4½	14½ 5	12 4	9 3½	5 2½	2 2	-½ 2	-1½ 3½	1½ 5½	AM	22
22	AM	0 8	1½ 11	3½ 13	5 14	5½ 14	5½ 12	5 9½	4 6½	3 3	3 ½	3½ -1	5 1½	PM	
	PM	7 -½	9 1	11½ 3	13 5	13 6	12 7	9½ 6½	6½ 5½	3½ 4½	1 4	-½ 4	-1 4½	AM	23
23	AM	-1 5½	1 7½	3 9	5 11	7 11½	8 11	8 9½	7½ 7	6 4½	5½ 2	4½ 0	4½ -1	PM	
	PM	5 -1	6 0	7½ 2	9 4½	10 6½	10 8½	9 9	7 9	4½ 8½	2 7	0 6	-1 5	AM	24
24	AM	-1 5	-½ 5	1½ 6	4 7	7 8	9 [illegible]½	10 8	11 7	10 5	9 3	7½ ½	6 -1	PM	
	PM	5 -1½	4½ -1	4½ 1	5½ 3	6 6	7 9	7 11	6 12	5 12	3 11	1 9	-½ 7½	AM	25
25	AM	-1½ 5½	-1½ 4	0 3½	2 4	5 4½	8 5	11 5½	13 5½	13½ 4½	13 3	11 1½	9 0	PM	
	PM	6½ -1½	4½ -2	3 -1	2½ 1	3 4	3½ 7½	4 11	4½ 13	4 14½	3 14½	1½ 13	0 11	AM	26
26	AM	-1½ 8	-2 5½	-1½ 3	0 2	3 1½	7 1½	10½ 2½	13½ 3	15½ 3	16 2½	15 1½	12½ 0	PM	
	PM	9½ -1½	6 -2	3 -2½	1 -1	½ 1½	0 5	1 9	1½ 12½	2½ 15½	2 17	1½ 16½	0 15	AM	27
27	AM	-1½ 11	-2½ 8	-3 4	-2 1	½ -½	4 -1	8 -½	12 ½	15½ 1	17½ 1½	18 1	16 ½	PM	
	PM	13 -1	9 -2½	5 -3	2 -2½	-½ -1	-2 2½	-2 6½	-1 11	0 15	1 18	1 19	½ 18	AM	28
28	AM	-1 15	-2 11	-3½ 6½	-3½ 3	-2 -½	½ -2	4½ -2½	9½ -2	14 -1	17 0	19 1	19 ½	PM	
	PM	17 -½	13 -2	8½ -3	4 -3½	0 3	-2½ -½	-3½ 3	-3 8	-2 13	-½ 17	½ 19	½ 20	AM	29
29	AM	0 18	-1½ 14½	-3 10½	-4 5½	-3½ 1	-2 -2	1½ -3½	6 -3½	11 -2½	15½ -1	19 0	20 ½	PM	
	PM	19 0	16 -1	12 -2½	7 -3½	2 -4	-1½ -2½	-3½ 0	-4 4½	-3½ 9½	-2 14	-½ 18	½ 20	AM	30
30	AM	½ 19½	-½ 17	-2 13	-3½ 8	-4 3	-3 -1	-1 -3½	2½ -4½	7½ -3½	12 -2½	16½ -1	19½ ½	PM	
	PM	20 1	18½ 0	15 -1½	10 -2½	5 -3½	½ -3½	-2½ -1½	-4 2	-4 6½	-3 11½	-1 16	½ 19	AM	
31	AM													PM	
	PM													AM	

Table 3

Month: July 1958

		0 h.		1 h.		2 h.		3 h		4 h.		5 h		6 h		7 h		8 h		9 h		10 h.		11 h			
		12 h.		13 h.		14 h		15 h		16 h		17 h		18 h		19 h		20 h.		21 h.		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105 E	
75° W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	1	20	1	18 1/2	0	15 1/2	-2	11	-3	6	-3 1/2	1 1/2	-2 1/2	-2	0	4	4	-4	9	-3	13 1/2	-1 1/2	17	1/2	PM	Dates 1
	PM	19	1 1/2	19	1 1/2	17	1/2	13	-1	8	-2 1/2	3	-3	-1	-2 1/2	-3	1/2	-4	3	-3 1/2	7 1/2	-2	12 1/2	0	16 1/2	AM	2
2	AM	1 1/2	19	2	19	1 1/2	17	0	13 1/2	-1 1/2	9	-2 1/2	4	-2	0	-1	2 1/2	2 1/2	-3 1/2	6 1/2	-3	11	1 1/2	15	0	PM	
	PM	18	2	18 1/2	2 1/2	17	2	14	1	9 1/2	-1/2	5	1 1/2	1	2	-2	1	-3	1 1/2	-3	5	-2	9 1/2	0	13 1/2	AM	3
3	AM	2	16 1/2	3	18	3	17	2	14 1/2	1	11	-1/2	6 1/2	-1	2 1/2	-1/2	1	1	-2 1/2	4	-3	8	-2	12	0	PM	
	PM	15	2	17	3	17	3 1/2	15	3	11 1/2	2	7	1/2	3	0	0	0	-2	1	-2 1/2	3 1/2	-2	7	0	10 1/2	AM	4
4	AM	2	14	3 1/2	16	4	16 1/2	4	15	3	12	2	8 1/2	1	4 1/2	1/2	1	1	-1	3	-2	6	1 1/2	9 1/2	0	PM	
	PM	12 1/2	1 1/2	14 1/2	3 1/2	15 1/2	4 1/2	14 1/2	5	12	4 1/2	9	3	5	2	2	1 1/2	-1/2	1 1/2	-2	3 1/2	-1 1/2	5	0	8	AM	5
5	AM	2	11	3 1/2	13	5	14 1/2	5 1/2	14	5	12 1/2	4 1/2	9 1/2	3	6	2 1/2	3	2 1/2	0	3 1/2	-1	5	1 1/2	7 1/2	1/2	PM	
	PM	10	1	12	3	13 1/2	5	13	6	12	6	9	5 1/2	6	4 1/2	3	4	1/2	3 1/2	-1	3 1/2	-1	5	1/2	6 1/2	AM	6
6	AM	1	9	3	11	5	12	6	12 1/2	7	11 1/2	6 1/2	9 1/2	5 1/2	7	5	4	4 1/2	1	4 1/2	-1/2	5	-1	6	-1/2	PM	
	PM	8	1	10	2 1/2	11	4 1/2	11 1/2	6	11	7	9	7 1/2	7	7	4	6	2	5 1/2	0	5	1	5 1/2	1/2	6	AM	7
7	AM	1/2	7 1/2	2	9	4 1/2	10	6	10 1/2	7 1/2	10	8	9	8	7	7	4 1/2	6 1/2	2	6	1/2	5 1/2	-1	6	-1/2	PM	
	PM	7	0	8	1 1/2	9	4	9 1/2	5 1/2	9	7	8	8	6 1/2	8 1/2	4 1/2	8	2 1/2	7 1/2	1/2	7	-1/2	6 1/2	-1	6	AM	8
8	AM	0	6 1/2	1 1/2	7	3 1/2	8	5 1/2	8	7	8	8 1/2	7 1/2	9	6 1/2	9	5	8 1/2	3	[illegible]	1	7	0	6 1/2	-1	PM	
	PM	6	-1/2	6 1/2	1/2	7	2 1/2	7	4 1/2	7	6 1/2	6 1/2	8 1/2	6	9 1/2	4 1/2	10	3	10	1	9	0	8	-1	7	AM	9
9	AM	-1	6 1/2	0	6	2	6	4	6	6	6	8 1/2	5 1/2	10	5	10 1/2	4	10 1/2	3	10	1 1/2	9	0	8	1	PM	
	PM	6 1/2	1	5 1/2	-1/2	5	1	5	3	5	5 1/2	4 1/2	8	4 1/2	10	3 1/2	11	2 1/2	11 1/2	1 1/2	11	0	10	-1	8 1/2	AM	10
10	AM	-1	7	-1	6	0	5	2	4	5	4	7	3 1/2	9 1/2	3 1/2	11 1/2	3	12 1/2	2 1/2	12	1 1/2	11	1/2	9 1/2	1/2	PM	
	PM	8	-1 1/2	6	-1 1/2	4	-1/2	3 1/2	1	3	4	2 1/2	6 1/2	2 1/2	9	2 1/2	11 1/2	2	13	1 1/2	13	1/2	12 1/2	1/2	11	AM	11
11	AM	-1 1/2	8 1/2	1 1/2	6 1/2	-1	4 1/2	1/2	3	3	2	6	1 1/2	9	1 1/2	11 1/2	2	13 1/2	2	14	1 1/2	13 1/2	1/2	12	-1/2	PM	
	PM	9	1 1/2	7	-2	4	-1 1/2	2	1/2	1	1 1/2	1/2	4 1/2	1/2	8	1	11	1 1/2	13 1/2	1	15	1/2	14 1/2	-1/2	13	AM	12
12	AM	1 1/2	10 1/2	2	7 1/2	-2	4 1/2	-1	2	1	1 1/2	4	0	7	0	10 1/2	1/2	13 1/2	1	15	1	15 1/2	1/2	14	0	PM	
	PM	12	1 1/2	8 1/2	-2	5 1/2	2 1/2	2 1/2	-2	1/2	0	-1	3	-1	6 1/2	1/2	10	0	13 1/2	1/2	16	1/2	16 1/2	0	15 1/2	AM	13
13	AM	-1	13	2	10	2 1/2	6	-2 1/2	3	1	0	1	1	5	1 1/2	9	1	13	1/2	15 1/2	1/2	17	1	16 1/2	1/2	PM	
	PM	15	-1/2	11 1/2	-2	7 1/2	-3	3 1/2	-3	1/2	-2	1 1/2	0	-2	4	2	8	-1	12	0	15 1/2	1/2	17 1/2	1/2	18	AM	14
14	AM	0	16	1 1/2	13	2 1/2	9	-3																			

15	PM	19½	1½	17½	½	14	-1	9	-2½	4	-3½	0	-3	-2½	-1	-3½	2½	-3	7	1½	12	0	16½	1½	19	AM	16
16	AM	2	20	1½	18½	0	15	-2	10½	-3	5½	3½	1	-2	-2	1	-3	5½	-3	10	1½	15	0	18	2	PM	
	PM	20	2½	19	2	16½	1	12	-1	7	-2½	2½	3	-1	-2½	-3	0	-3	4	2	9	0	14	2	17½	AM	17
17	AM	3	19½	3	19½	2	17½	0	13½	-2	9	-3	4	2½	0	-½	2½	3	-3	8	-2	13	0	17	2	PM	
	PM	19	3½	19½	4	17½	3	14	1½	9	-½	4½	2	½	2½	-2	-1½	2½	1½	-2	6	0	10	2	14½	AM	18
18	AM	4	18	4½	19½	4	18	2½	15	½	11	-1	6	-2	2	1½	-1	1	2½	4½	-2	9	0	13½	2	PM	
	PM	17	4	18½	5	18	5½	15½	4	11½	2	7	0	2½	-1	½	-1	-2	0	-2	3	-½	7½	2	12	AM	19
19	AM	4	15	6	17	6½	17½	5½	16	4	12½	2	8	0	4	½	½	0	1½	2	-2	5½	-1	10	1½	PM	
	PM	13½	4	16	6	16½	7	15½	7	13	5½	9	3½	5	1½	1½	½	-1	½	-1½	2	-1	4½	1	8	AM	20
20	AM	3½	11½	6	14	7½	15½	8	15	7	13	5	10	3	6	1½	2	1	0	2	1½	3½	-1	6½	½	PM	
	PM	9½	3	12	5½	14	7½	14	8½	12	8	9½	7	6	5	2½	3½	0	2	-1	2	-1	3	0	5	AM	21
21	AM	2½	8	5	10½	8	12	9	12½	9½	11½	8½	9	7	6½	5	3½	3½	½	3	-1	3	-1	4½	0	PM	
	PM	6½	2	8½	4½	10	7	11	9	10½	10	9	10	6½	9	4	7	1	5½	-½	4	-1	3½	-½	4	AM	22
22	AM	1	5	3½	6½	6½	8	9	9	10½	9	11	8	10½	6	9	4	7	1½	5½	0	4½	-1	4	-1	PM	
	PM	4½	½	5	3	6½	5½	7	8	7½	10	7	11½	6	11½	4	11	2	9	0	7½	-1	6	-1	4½	AM	23
23	AM	0	4	2	4½	4½	5	7½	5½	10	6	12	5½	12½	5	12	3½	11	2	9	0	7	-1	5½	-1½	PM	
	PM	4	-1	3½	1	3½	3	4	6	4	9	4	11	4	13	3	13½	1½	13	0	11	-1	9	-1½	7	AM	24
24	AM	-1	5	0	3½	2	3	5	2½	8	2½	11	3	13	3	14	2½	14	1½	13	½	11	-½	8	-1½	PM	
	PM	6	1½	4	-1	2	1	1½	3	1	6½	1½	10	1½	12½	1½	14½	1	15	½	14½	-½	13	-1½	10	AM	25
25	AM	-2	7½	-1½	5	0	2½	2	1	5	0	8½	0	12	½	14½	1	16	1	15½	½	14½	0	12	-1	PM	
	PM	9	-2	5½	-2	2½	-1	½	½	-½	3	-1	7	-½	10½	0	13½	½	16	½	16½	0	16	-1	14	AM	26
26	AM	-1½	10½	-2	7	-2	4	-½	1	2	-1	5½	-1½	9½	1½	13	-1	16	0	17	½	17	0	15	-½	PM	
	PM	12	-1½	8	-2	4½	-2½	1	-1½	-1	½	-2	3½	-2	7½	-1½	11	½	15	½	17	½	18	0	17	AM	27
27	AM	-1	14	-2	10	2½	6	-2	2	½	-1	2	-2½	6	3	10	-2	14	-1	17	0	18½	½	17½	½	PM	
	PM	15	0	11½	-1½	7	-2	3	2½	0	-1½	-2	½	-3	4½	-2½	8½	-1½	13	0	16½	1	18	1	18½	AM	28
28	AM	½	16½	-½	13	-2	9	-2½	4½	-2	½	-½	-2	2½	3	6½	-3	11	1½	15	0	18	1	19	1½	PM	
	PM	17½	1	14½	0	10	1	5½	-2½	1½	-2½	1½	1½	3	1½	-3	5	-2	10	0	14	1½	17	2½	19	AM	29
29	AM	2	18	1	15½	½	12	-2	7	-2½	3	-2	-½	½	-2½	4	-3	8½	-2	13	0	16½	1½	18½	3	PM	
	PM	18½	3	16½	2	12½	½	8	-1	3½	-2	0	-2	-2	-½	-3	2½	-2	6½	0	11	2	15	3½	18	AM	30
30	AM	4	18½	3	17	1½	13½	0	9½	1½	5	-2	1	-1	-1½	1½	2½	5½	-2	10	0	14	2	17	4	PM	
	PM	18	4½	17	4	14½	3	10½	1	6	-1	2	-1½	-1	-1	-2	1	-2	4½	0	8½	2	13	4	15	AM	31
31	AM	5½	17½	5½	17	4	15	2	11	½	7	-1	3	-1	0	0	-2	3	-1½	7	0	11	2	14½	4	PM	
	PM	17	6	17	6	15½	5	12	3½	8	1½	4	0	½	½	-1½	0	-1½	2½	0	6	2	10	4	13½	AM	

Table 3

Month: August 1958

		0 h.		1 h		2 h.		3 h.		4 h.		5 h.		6 h.		7 h		8 h.		9 h		10 h		11 h			
		12 h		13 h.		14 h		15 h.		16 h.		17 h.		18 h.		19 h.		20 h.		21 h		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105 E	
75° W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	6½	16	7	16½	6½	15½	5	12½	2½	9	1	4½	0	1	½	–1	2	1½	5	0	9	2	12½	4	PM	Dates 1
	PM	15	6½	16	7½	15	7½	12½	6	9	4	5	2	1½	1	½	½	–1	2	0	4½	2	7½	4	11	AM	2
2	AM	6½	13½	8	15	8	15	7	13	5	10	3	6	1½	2½	1	0	2	–1	4	–½	7	1½	10	3½	PM	
	PM	12½	6	14	8	14	8½	12½	8	10	6½	6	4½	3	3	½	2	–½	2	–½	3½	1	6	3½	9	AM	3
3	AM	6	11½	8	13	9	13½	9	12½	7½	10	6	7	4	3½	3	1	2½	–½	3½	½	5½	½	8	3	PM	
	PM	10	5½	12	7½	12½	9	11½	9	9½	8½	7	7	4	5	1½	4	0	3	–½	3½	½	5	2½	7	AM	4
4	AM	5	9	7½	11	9	11½	9½	11	9	9½	8	7	6	4	4½	1½	4	0	4	–½	5	½	6½	2	PM	
	PM	8	4½	10	7	10½	8½	10	9½	9	9½	7	8½	4	7½	2	6	0	5	½	4½	0	5	1½	6	AM	5
5	AM	4	7	6	8½	8	9½	9½	9½	10	.8	9½	6½	8	4	7	2	5½	½	5	½	5	0	5½	1	PM	
	PM	6½	3	7½	5	8	7½	8½	9	7½	10	6	10	4	9	2	8	½	7	–½	6	½	5½	½	5½	AM	6
6	AM	2	6	4½	6½	7	7	8½	7½	10	7	10½	5½	10	4	9	2½	8	½	6½	–½	6	½	5½	0	PM	
	PM	5½	1½	6	3½	6	6	6	8	6	9½	5	10½	3½	10½	2	10	1	9	0	7½	–½	6½	0	6	AM	7
7	AM	1	5½	3	5½	5	5	7	5	9	5	10½	4	11	3	10½	2	10	1	9	0	7½	1	6½	½	PM	
	PM	5½	½	4½	2	4½	4	4	6	4	8½	3½	10	2½	11	2	11½	1	11	0	10	½	8½	–½	7	AM	8
8	AM	0	5½	1	4½	3	4	5	3½	7½	3	9½	2½	11	2	12	1½	12	1	11	0	9½	–1	8	–1	PM	
	PM	6	½	4½	½	3	2	2½	4	2	6½	2	9	1½	11	1½	12½	1	13	½	12½	–½	11	1	9	AM	9
9	AM	–1	7	0	5	1	3	3	2	5½	1½	8	1	10½	1	12½	1	13½	1	13½	½	12½	0	10½	–½	PM	
	PM	8	–1	5½	½	3	0	1½	2	½	4½	½	7	½	10	½	12½	1	14	½	14½	0	13½	½	12	AM	10
10	AM	–1	9	–1	6	½	3½	1	1	3	0	6½	½	9½	0	12	½	14½	1	15½	1	15	½	13	0	PM	
	PM	10½	–1	7½	1	4	–1	1½	0	0	2	1	5	–½	8½	0	12	1	14½	1½	16	1	16	½	14½	AM	11
11	AM	0	12	–1	8½	1½	5	–1	2	1	0	3½	–1	7	–1	11	–½	14	½	16½	1½	17	2	16	1½	PM	
	PM	13½	½	10	–1	6	1½	2½	–1½	0	0	1½	2	1½	6	–1	10	½	14	2	16½	2½	18	2	17	AM	12
12	AM	1	15	0	11½	–1½	7½	–2	3½	–1	0	1	1½	4	–2	8	1	12½	½	16	2	18	3	18½	3	PM	
	PM	16½	2	13	½	9	–1	4½	2	1	–2	–1	0	–2	3	–1½	7	0	11½	2	15½	3½	18	4	19	AM	13
13	AM	3	18	1½	14½	0	10½	–2	6	–2½	2	–1	–1	1½	–2	5½	1½	10	0	14½	2	18	4	19	5	PM	
	PM	18½	4½	16	3	12	1	7	–1	3	–2	0	–2	–2	0	1½	3½	0	8½	2	13	4½	17	5½	19	AM	14
	AM	5½	19	4½	17	2	13½	0	9																		

15	PM	18 8½	18 8½	16 7	12 4½	7½ 1½	3 −1	0 −2	−1½ −1	−1 1½	1 5½	4 10	7 14	AM	16
16	AM	9½ 17	10 17½	8½ 16	6 12½	3 8	0 4	−1 ½	−1 −1	1 −1	4 1	8½ 4	12½ 7	PM	
	PM	15½ 9½	17 10½	16 10	13 8	9 5	5 1½	1 −½	−1 −1	−1 0	½ 3	3 7	6½ 11	AM	17
17	AM	9½ 14	11 15½	11 15	9½ 13	7 9½	4 5½	1 2	0 ½	0 −1	1½ 0	5 2½	8½ 6	PM	
	PM	12 9	14 11½	14½ 12	13 11	10 8½	6 5½	2½ 2½	0 1	−1 0	½ 1	2 3½	5 7	AM	18
18	AM	8½ 10	11 12	12½ 13	12 12	10½ 9½	8 6½	5 3	2 ½	1 −1	1 ½	2½ 1½	5 4½	PM	
	PM	8 8	10 10½	11 12½	11 13	9 11½	6½ 10½	3½ 6½	1 4	−½ 2	1 1½	½ 2	3 4	AM	19
19	AM	7 6½	10 8½	12½ 9½	13½ 9½	13 8	10½ 6	8 3½	5½ 1	3½ −½	2½ 1	2½ 0	3 2½	PM	
	PM	5 6	6½ 9	8 11½	8 13	7 13½	5½ 12	3 10	1 7½	−½ 5½	−1 3½	0 2½	2 3	AM	20
20	AM	5 4	8 5	11 6	13 6½	13½ 6	13 5	11½ 3	9½ 1½	7 0	5 −1	3½ ½	3 1	PM	
	PM	3 3	3½ 6	4½ 9	5 12	5 13	4 13½	3 13	1½ 11½	0 9	−½ 7	−½ 5	½ 3½	AM	21
21	AM	2½ 3	5 3	8 3	10½ 3½	12½ 3½	14 3	14 2½	13 1½	11 0	9 −½	6½ −1	4½ 0	PM	
	PM	3 1	2½ 3½	2 6	2 9	2 11½	2 13	2 14	1 14	½ 12½	½ 10½	−½ 8	−½ 6	AM	22
22	AM	½ 4	2½ 2	5 1½	7½ 1	10 1	12½ 1	14 1	14½ 1	14 ½	12 0	10 −½	7½ −½	PM	
	PM	5 0	3 1½	1 3½	½ 6	0 9	0 11½	½ 13½	1 14½	½ 14½	½ 13½	0 11½	0 9	AM	23
23	AM	0 6	½ 3½	2 1	4 0	7 −½	10 −½	12½ 0	14½ ½	15 1	15 1	13 ½	10½ 0	PM	
	PM	7½ 0	4½ ½	2 1	0 3	−1 5½	−1 8½	−½ 11½	0 14	1 15½	1½ 15½	1 14	½ 12	AM	24
24	AM	0 9	0 5½	½ 2½	1½ 0	3½ −1	6½ −1½	9½ −1	12½ 0	15 1	16 1½	15½ 2	14 1½	PM	
	PM	11 ½	7 0	3½ 0	1 ½	−1 2½	−2 5	1½ 8½	0 11½	1 14½	2 16	2½ 16	2 14½	AM	25
25	AM	1½ 12	½ 8½	0 4½	0 1½	1½ −1	4 −1½	7 −1½	10½ −½	14 1½	16 2½	16½ 3½	15½ 3½	PM	
	PM	13 2½	9½ 1	5½ 0	2 ½	½ ½	−1½ 2	−1½ 5½	0 9	1½ 12½	3 15	4 16½	4 16	AM	26
26	AM	3½ 14½	2 11	½ 7	0 3½	0 0	1½ −1	4 −1½	7½ −½	11½ 1½	14½ 3½	16½ 5	16½ 5½	PM	
	PM	15 4½	12 3	8 1½	4 0	1 ½	−1 ½	−1 2½	0 6	1½ 10	4 13½	5½ 16	6½ 17	AM	27
27	AM	6 16	4½ 13	2½ 9½	½ 5½	½ 2	0 −½	−1½ −1	4½ 0	8½ 1½	12½ 4	15 6	16½ 7	PM	
	PM	16 7	14 5½	10 3½	6 1½	2½ 0	0 ½	1 1	0 3½	1½ 7	4 11	6½ 14	8 16	AM	28
28	AM	8 16	7 14	4½ 11	2 7	½ 3	½ ½	½ ½	2½ 0	6 1½	10 4½	13½ 7	15½ 8½	PM	
	PM	16 9	14½ 8	11½ 6	7½ 3½	4 1	1 0	½ 0	0 2	1½ 5	4 8½	7 12	9 15	AM	29
29	AM	10 15½	9 15	7½ 12	4½ 8½	2 5	½ 1½	0 0	1½ 0	4 1½	7½ 4	11 7	14 9	PM	
	PM	15 10½	14½ 10½	12 8½	9 6	5 3½	2 1	0 ½	0 1	1 3	4 6	7 10	9½ 12½	AM	30
30	AM	11 14½	11 14½	10 12½	7½ 9½	4½ 6	2 2½	1 ½	1 0	2½ 1	5½ 3½	8½ 6	11½ 9	PM	
	PM	13½ 11	14 12	12½ 11	9½ 8½	6 5½	3 3	1 1½	0 1	1 2	3 4½	6 7½	9 10½	AM	
31	AM	11½ 12½	12½ 13	11½ 12	9½ 9½	6½ 6½	4 3	2 1	1½ 0	2 ½	4 2½	7 5½	9½ 8½	PM	
	PM	11½ 11	12½ 12½	11½ 12	9½ 10½	6½ 8	3½ 5	1 3	0 1½	½ 2	2 3½	5 5½	8 8	AM	

Table 3

Month: September 1958

		0 h.		1 h		2 h		3 h		4 h		5 h.		6 h		7 h		8 h		9 h		10 h		11 h			
		12 h		13 h		14 h.		15 h.		16 h.		17 h		18 h		19 h		20 h		21 h		22 h.		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105 E	
75° W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	11	10 1/2	12 1/2	11 1/2	12 1/2	11	11	9 1/2	9	6 1/2	6	4	4	1 1/2	2 1/2	0	2	0	3	1 1/2	5	4	7	7	PM	Dates 1
	PM	9 1/2	10	10 1/2	12	10	12 1/2	8 1/2	12	6 1/2	10	4	7 1/2	1 1/2	5	0	3	0	2 1/2	1	3	3 1/2	4	6 1/2	6	AM	2
2	AM	9 1/2	8	12	9	12 1/2	9 1/2	12	8 1/2	10 1/2	6 1/2	8 1/2	4	6	2	4	0	3	-1/2	3	1/2	4	3	5 1/2	5 1/2	PM	
	PM	7	8 1/2	8	11	8 1/2	12	7 1/2	12 1/2	6	11	4	9 1/2	2	7	0	5	-1/2	3 1/2	1/2	3	2	3 1/2	5	4 1/2	AM	3
3	AM	8	6	10 1/2	7	12	7 1/2	12 1/2	7	12	5 1/2	10	3 1/2	8	2	6	1/2	4 1/2	-1/2	3 1/2	0	3 1/2	2	4	4	PM	
	PM	5 1/2	7	6	9 1/2	6 1/2	11 1/2	6	12	5	12	3 1/2	10 1/2	2	9	1/2	7	-1/2	5	0	4	1	3 1/2	3	4	AM	4
4	AM	6	4 1/2	8 1/2	5	10 1/2	5 1/2	12	5	12	4 1/2	11 1/2	3	10	2	8	1/2	6 1/2	-1/2	5	1/2	4 1/2	1/2	4	2 1/2	PM	
	PM	4	5	4 1/2	7 1/2	4 1/2	9 1/2	4 1/2	11	4	12	3	10 1/2	2	11 1/2	1/2	9	0	7 1/2	0	6	1/2	4 1/2	2	4	AM	5
5	AM	4	4	6	4	8 1/2	4	10 1/2	3 1/2	11 1/2	3	12	2 1/2	11 1/2	1 1/2	10 1/2	1/2	9	0	7	-1/2	6	0	4 1/2	1	PM	
	PM	4	3	3 1/2	5	3	7 1/2	3	9 1/2	2 1/2	11	2	12	1 1/2	12	1	11	0	10	0	8	0	6 1/2	1 1/2	5	AM	6
6	AM	2 1/2	4	4 1/2	3	6 1/2	2 1/2	8 1/2	2	10 1/2	2	12	1 1/2	12 1/2	1 1/2	12	1	11	1/2	9 1/2	0	8	1/2	6	1	PM	
	PM	4	2	3	3 1/2	2	5 1/2	1 1/2	7 1/2	1 1/2	9 1/2	1	11 1/2	1	12 1/2	1	13	1	12 1/2	1/2	11	1/2	9	1	7	AM	7
7	AM	1 1/2	5	2 1/2	3	4	2	6	1	8 1/2	1 1/2	11	1	12 1/2	1	13 1/2	1 1/2	13 1/2	1 1/2	12 1/2	1	10 1/2	1	8 1/2	1	PM	
	PM	6	1	4	1 1/2	2	3	1	5	1/2	7	1/2	10	1	12	1 1/2	13 1/2	2	14	2	13 1/2	1 1/2	12	1	10	AM	8
8	AM	1	7	1	4 1/2	2	2	3 1/2	1/2	6	0	8 1/2	0	11	1	13 1/2	1 1/2	15 1/2	2 1/2	15	3	13 1/2	2 1/2	11	2	PM	
	PM	8 1/2	1 1/2	5 1/2	1	2 1/2	1 1/2	1/2	2 1/2	0	4 1/2	0	7	1/2	10	2	13	3	15	3 1/2	15 1/2	3 1/2	15	3	13	AM	9
9	AM	2	10	1	6 1/2	1/2	3 1/2	1 1/2	1	3	1/2	6	-1/2	9	1/2	12	2	15	3 1/2	16	4 1/2	16	4 1/2	14	4	PM	
	PM	11	2 1/2	8	1 1/2	4	1/2	1	1/2	0	1 1/2	-1/2	4	1/2	7 1/2	2	11	4	14	5	16	6	17	5	15 1/2	AM	10
10	AM	4	13	2	9 1/2	1/2	5 1/2	0	2	1/2	0	3	1/2	6	0	9 1/2	2	13	4	16	6	17	7	16 1/2	6 1/2	PM	
	PM	14	5 1/2	10 1/2	3 1/2	6 1/2	1	2 1/2	0	0	1/2	1/2	1	0	4	2	7 1/2	4	12	6 1/2	15	8	17	8	17	AM	11
11	AM	7	15 1/2	4 1/2	12	2	8	0	4	-1	1	0	-1	2	-1/2	6	1 1/2	10	4	14	7	16 1/2	9	17 1/2	9 1/2	PM	
	PM	16	8 1/2	13	6 1/2	9	3 1/2	4 1/2	1	1	-1	1/2	1	1/2	1/2	1	4	4 1/2	8	7	12 1/2	9 1/2	15 1/2	11	17	AM	12
12	AM	10	16 1/2	8	14	5	10	1 1/2	5 1/2	-1	2	1 1/2	1/2	0	-1	2 1/2	1	7	4	11	7	15	10	17	12	PM	
	PM	16 1/2	12	14 1/2	10	10 1/2	6 1/2	6	3	2 1/2	0	0	-1 1/2	-1	-1	1/2	1	3 1/2	5	7	9	10 1/2	13	12 1/2	15 1/2	AM	13
13	AM	13	16 1/2	11 1/2	15	9	11 1/2	5	7	1	3	-1	0	-1 1/2	-1	0	0	3	2 1/2	7	6	11	10	14	13	PM	
	PM	15 1/2	14	14 1/2	13	12	10 1/2	8	7	4	3	1/2	0	1	-1 1/2	1/2	-1	2	1	5 1/2	5	9 1/2	9	13	12 1/2	AM	14

15	AM	15 11	16½ 12	15 11	12½ 8½	9 5½	4½ 2	-½	−½ -1	1 0	1 3	3½ 7	[illegible] 11		
	PM	9 14½	10½ 16½	10 16½	8 14	5 10½	2 6½	0 3	-1 0	-½ -½	2 0	6 2	10 5	AM	16
16	AM	14 7	16 9	17 9	15½ 8	12½ 5½	8½ 2½	5 ½	2 −1	0 -1	0 1	1 4	3 8½	PM	
	PM	5½ 12	7 15	7½ 16½	7 16	5 14	2½ 10½	½ 7	-1 3½	-1 1	½ ½	3 ½	7 2	AM	17
17	AM	11 4	14 5½	16 6	16½ 6	15 4½	12 3	9 1	5½ ½	2½ −1	1 0	½ 2	1½ 5½	PM	
	PM	2½ 9	4 12½	4½ 15	4½ 16	4 15½	2½ 13½	1 10½	-½ 7½	-1 4½	½ 2	1½ 1	4½ 1	AM	18
18	AM	8 1½	11 2½	14 3½	15½ 3½	15½ 3	14 2	12 1	9 0	6 ½	4 -½	2 1	1 3	PM	
	PM	1 6½	1½ 9½	2 12½	2½ 14	2½ 15	2 14½	1 13	0 11	½ 8	0 5½	½ 3	2½ 2	AM	19
19	AM	5 1	8 1	10½ 1	13 1½	14 1½	14½ 1½	14 1	12 ½	9½ 0	7 0	4½ ½	3 2	PM	
	PM	1 4	½ 6	½ 9	½ 11	1 13	1 14	1 14	1 13	½ 11	½ 9	1 6½	1½ 4	AM	20
20	AM	3 2	5 1	7 0	9½ 0	11½ 0	13 ½	14 1	13½ 1	12½ 1½	10½ 1½	8 1½	5½ 1½	PM	
	PM	3 2½	1 3	0 5½	½ 8	½ 10	0 12	1 13½	1½ 14	2 13	2 11½	2 9½	2 7	AM	21
21	AM	2½ 4	3 2	5 0	6½ -½	8½ -½	11 0	12½ 1	14 2	13½ 2½	12½ 3	10½ 3	8 2½	PM	
	PM	5 2½	2½ 3	½ 3½	-½ 5	-1 7	½ 9	1 11½	2 13	3 14	3½ 13½	3½ 12	3½ 9½	AM	22
22	AM	3 7	2½ 4	3 1½	4 0	5½ -1	8 ½	10 1	12½ 2	14 3½	14 4½	13 5	10½ 4½	PM	
	PM	7½ 3½	4½ 3	2 2½	0 3	1 4	-½ 6	1 8½	2½ 11	4½ 13	5½ 14	6 13½	5½ 12	AM	23
23	AM	4½ 9	3 [illegible]	2½ 3	2 ½	3 -½	5 ½	7½ 1	10 2½	11½ 5	14 6	14 7	12½ 6½	PM	
	PM	10 6	7 4	3½ 3	1 2	0 2	0 3½	1 6	3 8½	5½ 11½	7 13½	8 14	8 13	AM	24
24	AM	7 11	5 8	3 4½	2 2	1½ 0	3 0	5 1	8 3	11 5½	13 8	14 9	13½ 9	PM	
	PM	11½ 8	8½ 6	5 4	2 2	½ 1½	0 2	1 3½	3 6½	6 9½	8½ 12	10 13½	10½ 13½	AM	25
25	AM	9½ 12	7½ 9½	5 6	2½ 3	1½ 1	1½ 0	3 1	5 3	8 6	11 8½	13 10½	13½ 11½	PM	
	PM	12½ 10½	10 8½	6½ 6	3½ 3½	1 1½	0 1	1 2	3 4	6 7	9 10	11 12½	12½ 13½	AM	26
26	AM	12 12½	10 10½	7 7	4 4	2 1½	1 ½	1 ½	3 2½	6 5½	9 8½	11½ 11½	13 13	PM	
	PM	12½ 13	10½ 11	8 8½	4½ 5	2 2½	½ 1	½ 1	2 2	5 4½	8½ 8	11½ 10½	13½ 12	AM	27
27	AM	14 12	12 10½	9½ 7½	6 4½	3 2	1 ½	½ ½	1½ 2	4 5	7 8½	9½ 12	11½ 14	PM	
	PM	12 14½	10 13	8 10½	5 7	2 4	½ 1½	½ ½	1½ 1	4½ 3	8 6	11 8½	14 10½	AM	28
28	AM	15 11½	14 10½	12 8	8½ 5½	5 2½	2 ½	½ 0	½ 1	2 4	5 7	7½ 11	9½ 13½	PM	
	PM	10½ 15	10 15	8 12½	5½ 9½	3 6	½ 3	0 1	½ ½	3 1½	6½ 3½	10 6	13 8½	AM	29
29	AM	15 10	15½ 9½	14 8	11 5½	7 3	4 1	1½ ½	½ ½	1 2½	3 6	5 9½	7½ 13	PM	
	PM	9 15	9 15½	7½ 14	5½ 11½	3 8	½ 5	-½ 2	0 1	2 1	5 2	8 4	12 6½	AM	30
30	AM	14½ 8	15½ 8	14½ 7	12½ 5½	9 3	5½ ½	3 -½	1 ½	1 1	1½ 4	3½ 8	5½ 11	PM	
	PM	7 14	7½ 15	6½ 15	5 13	3 10	1 7	-½ 4	-½ 1½	1 1	3½ 1½	7 2½	10½ 4	AM	
31	AM													PM	
	PM													AM	

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		0 h.		1 h.		2 h.		3 h.		4 h.		5 h.		6 h.		7 h		8 h		9 h		10 h		11 h			
		12 h		13 h		14 h.		15 h.		16 h.		17 h		18 h.		19 h		20 h		21 h.		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105° E	
75° W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	13½	5½	15	6½	15	6	13½	5	11	3	8	1	4½	−½	2½	−1	1	0	1	2½	2	5½	3½	9	PM	Dates 1
	PM	5	12	5½	14½	5	15	4	14	2½	12	1	9	−½	6	1	3½	0	2	2	1½	5	2	[illegible]	2½	AM	2
2	AM	11½	4	13½	4½	14½	4½	14	4	13	2½	10	1	7	−½	4½	−1	2½	−½	1½	1	1½	4	2	7	PM	
	PM	3	10	3½	13	4	14	3	14	2	13	1	11	0	8½	1	5½	½	3½	1	2	3	1½	6	2	AM	3
3	AM	9½	2½	12	3	13½	3½	14	3	13½	2	11½	1	9	0	7	½	4½	−½	3	½	2	2½	2	5½	PM	
	PM	2	8½	2½	11	2½	13	2	13½	1½	13½	1	12½	0	10½	½	8	−½	6	½	4	2	2½	4½	2	AM	4
4	AM	7	2	10	2	12	2	13	2	13½	1½	13	1	11½	½	9½	0	7	0	5	½	3½	1½	2½	3½	PM	
	PM	1½	6	1½	8½	1½	11½	1½	12	1	13	1	13	½	12	½	10½	0	8½	½	6½	1½	4½	3	3	AM	5
5	AM	5	2	7	1½	9½	1	11	1	12½	1	13	1	13	1	11½	1	10	1	8	1	5½	1½	3½	2½	PM	
	PM	2	4	1	6	1	8	1	10	1	11½	1½	13	1½	13	2	12½	2	11	2	9	2	7	2½	4½	AM	6
6	AM	3½	2½	5	1½	7	½	9	½	10½	1	12	1½	13	2	13	2½	12	2½	10½	2½	8	2½	6	2½	PM	
	PM	3½	3	2	4	½	5½	½	7½	½	9½	1½	11½	2½	13	3	13½	3½	13	3½	11½	3½	9	3	7	AM	7
7	AM	3	4½	3½	2	4	1	6	½	8	½	10	1½	12	2	13½	4	14	5	13	5	11	4½	8½	4	PM	
	PM	5½	3½	3	3	1	3½	0	4½	½	6	1	8½	3	11	4½	13	6	14	6½	13½	6	12	5	9½	AM	8
8	AM	4	6½	3	4	2½	1½	3	0	4½	0	7	1	9½	3	12	5	14	7	14	8	13	7½	11	6½	PM	
	PM	8	5	5	3½	2	2	0	2	0	3	1	5	3	8	5½	11	7½	13	9	14	9	14	8	12	AM	9
9	AM	6	9	4	5½	2	2½	1½	0	2	−½	4	½	7	3	10	5½	12½	8½	14	10½	14	11	12½	10	PM	
	PM	9½	8	6	5	3	2½	½	1	−½	½	½	2	3	4½	6	8	9	11	11½	13	12½	14	12	13	AM	10
10	AM	9½	10½	6½	7	3½	4	1	1	0	−½	½	0	3	2	6	5	9½	9	12	12	13½	14	13	13½	PM	
	PM	11	12	8	9	4	5	1	2	−½	0	−½	−½	1½	1	5	4	9	7½	12½	11½	15	12½	15	13	AM	11
11	AM	13½	11½	10½	9	6½	5	3	2	0	−½	−1	1	½	½	2	4	5½	8	9	12	11½	15	12½	16½	PM	
	PM	11½	15½	9	13	5½	9	2	4½	−½	½	−1½	1½	0	−1½	3	0	7	3	12	7	15½	10	17½	11½	AM	12
12	AM	17	11½	14½	9	10	6	6	2½	2	0	−1	1½	2	−1	−1	2	2	6	5	11	8½	15	10½	18	PM	
	PM	10½	18½	9	16½	6	13	3	8	0	3	1½	½	−1	−2	1	−2	5	0	10	3	14½	6	18	8½	AM	13
13	AM	19	9½	18	9	14½	6½	10	3½	5	½	1	−1½	2	−2	−2½	0	−1	3½	1	8	4	13	7	17	PM	
	PM	8½	19½	8	19	6	16½	3½	12½	½	7½	−1½	2½	−2	−1	−1	−2½	2½	−2	7	−½	12	2½	16½	5	AM	14
14	AM	19½	7	20	7½	18	6	14	4	9½	1	4½	−1	½	2	−2	1½	−2½	1	−1½	5½	1	10	3½	15	PM	

15	AM	17	4	19	5	19	4½	17	3½	13	1½	8	−½	4	−2	½	−2	−1½	0	−2	3	−1	7	½	11½	PM	15
	PM	2½	15½	3½	18	4	19	3	17½	1½	14½	½	10½	−1½	6	−2	2	−1	−½	2	1½	5½	−1½	10	−½	AM	16
16	AM	14	1	17	2½	18½	3	18	2½	15½	1½	12	0	8	−1	4	−1½	1	−1	−1	1	−1½	4	−1	8	PM	
	PM	0	12	1	15	2	17	2	17½	1½	16	0	13	1	9½	1	6	−1	2½	½	0	3	−1	6½	−1	AM	17
17	AM	10	−½	13½	½	16	1	16½	1½	16	1	14	½	11	0	7½	−½	4	½	1½	½	0	2½	−1	5½	PM	
	PM	−1	8½	½	11½	½	14	1	15½	1	15½	1	14½	½	12	0	9	0	6	1	3	2	1	4½	−½	AM	18
18	AM	7½	−1	10	−½	13	0	14	½	15	1	14	1	12½	1	10	1	7	1	4½	1½	2	2½	½	4	PM	
	PM	−½	6	−1	8½	−½	11	0	12½	½	13½	1	14	1½	13	1½	11½	2	9	2	6	2½	3½	4	1½	AM	19
19	AM	5	0	7	½	9½	−½	11	0	12½	½	13	1½	13	2	12	2½	9½	3	7	3	5	3½	2½	4	PM	
	PM	½	4½	½	6	−1	7½	−½	9½	½	11	1½	12	2½	12½	3½	12	4	10½	4	8½	4	6	4	4	AM	20
20	AM	4½	2	5	0	6½	−½	8	−½	9½	½	11	1½	12	3	12	4	11	5	9½	5	7½	5	5	5	PM	
	PM	2½	4½	½	5	0	5½	−½	6½	0	8	1½	9½	3	10½	5	11½	6	11½	6½	10½	6½	8½	6	6	AM	21
21	AM	5	3½	4½	1½	5	0	5½	0	6½	½	8	1½	10	3½	11	5½	11½	7	10½	7½	9	7½	7	7	PM	
	PM	4½	6	2	5	½	4½	0	4½	0	5½	1½	7	3½	8½	6	10	7½	11	8½	11	9	9½	8	7½	AM	22
22	AM	7	5½	5½	3	4½	1	4	0	4½	½	5½	1½	7	3½	9	6	10½	8	11	9½	10	10	8½	9½	PM	
	PM	6	8	3½	6	1½	4½	0	3½	0	3½	1½	4½	3½	6	6	8	9	9½	10½	10½	11	10	10½	9	AM	23
23	AM	9	6½	7	4	5	2	3½	½	3	0	3½	1½	5	3½	7	6½	9	9	10	11½	10½	12½	9	12	PM	
	PM	7½	10½	4½	8	2	5½	½	3½	0	2½	1	2½	3	3½	6	5½	9	8	12	9½	13	10	13	9½	AM	24
24	AM	11½	7½	9	5	6	2½	3½	½	2	0	2	1	3	3	4½	6	7	9½	9	12½	9½	14	9	14	PM	
	PM	8	12½	5½	10	3	7	1	4	0	2	½	1½	2½	2	5½	3½	9	6	12½	8	14½	9	15	9	AM	25
25	AM	14	8	11½	5½	8	3	5	1	2	0	1	0	1	2	2½	5	5	9	7	12	8½	15	9	15½	PM	
	PM	8	15	6	12½	3	9	1	5½	0	2½	0	1	1½	½	4	1½	8	3½	12	6	15	7½	16	8½	AM	26
26	AM	16	7½	14	6	10½	3½	6½	1½	3	−½	1	−½	0	1	1	3½	2½	7½	5	11½	6½	14½	7½	16½	PM	
	PM	7½	16½	6	14½	3½	11½	1	7½	0	4	−1	1	0	0	3	0	6½	1½	10½	4	14	5½	16½	7	AM	27
27	AM	17	7	15½	5½	12	3½	8½	1	4½	−½	1½	1	0	0	−½	2½	1	6½	3	10½	5	14	6	16½	PM	
	PM	6½	17	5½	16	3½	8	1½	9	½	5	−1	2	−½	0	1½	−1	5	0	9	2	13	4	16	5½	AM	28
28	AM	17½	6	17½	5	14	3½	10½	1½	6½	−½	3	−1½	0	−1	−1	1	−½	4½	1	8	2½	12½	4½	15½	PM	
	PM	5	17	5	17	3½	15	1½	11½	−½	7½	−1½	3½	−1½	½	0	−1	3	−1	7	0	11	2	15	3½	AM	29
29	AM	17	4½	17½	4	16	3	13	1½	9	½	5	1½	1½	2	−½	−½	−1	2½	−½	6	1	10½	2½	14	PM	
	PM	3½	16½	4	17½	3	16	1½	13½	0	9½	−1½	5½	−2	2	−1	0	1½	−1	5	−1	9	½	13	1½	AM	30
30	AM	16½	3	17	3	16½	2½	14½	1½	11	0	7	−1½	3½	−2	1	1½	−½	1	−1	4½	0	8	1	12	PM	
	PM	2	15	2½	17	2	16½	1	15	0	12	−1½	8	−2	4½	−1½	1½	½	0	3½	−1	7	½	11	½	AM	31
31	AM	14	1½	16	2	16½	2	15½	1	13	0	9½	−1	6	−2	3	1½	½	0	−½	2½	½	6	0	10	PM	
	PM	1	13	1½	15½	1½	16	1	15½	0	13½	−1	10	1½	7	−1½	4	0	1½	2	0	5	−½	8½	0	AM	

Table 3

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		0 h		1 h		2 h		3 h		4 h		5 h		6 h		7 h		8 h		9 h		10 h		11 h			
		12 h		13 h		14 h		15 h		16 h		17 h		18 h		19 h		20 h		21 h		22 h		23 h			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105 E	
75 W		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	12	1/2	14 1/2	1	16	1 1/2	16	1	14 1/2	1/2	12	1/2	8 1/2	–1	5	–1	2 1/2	–1/2	1	1 1/2	0	4	1/2	7 1/2	PM	Dates 1
	PM	0	10 1/2	1/2	13 1/2	1	15	1	15 1/2	1/2	14 1/2	0	12 1/2	–1/2	10	–1	6 1/2	0	4	1 1/2	1 1/2	3 1/2	1/2	6	0	AM	2
2	AM	9 1/2	0	12 1/2	1/2	14 1/2	1	15	1	14 1/2	1	13	1/2	10 1/2	0	8	0	5	1/2	2 1/2	1 1/2	1	3 1/2	0	5 1/2	PM	
	PM	0	8 1/2	0	11	1/2	13	1	14 1/2	1	14 1/2	1	13 1/2	1	11 1/2	1	9	1	6 1/2	1 1/2	3 1/2	3	1 1/2	5	0	AM	3
3	AM	7	0	9 1/2	0	12	1/2	13	1	14	1 1/2	13 1/2	2	12	2	10	2	7 1/2	2	5	2	3	3	1	4 1/2	PM	
	PM	0	6	0	8	1/2	10 1/2	1	12	2	13	2 1/2	13	3	12 1/2	3	11	3	9	3	6	3 1/2	4	4	2	AM	4
4	AM	5	1/2	7	0	8 1/2	1/2	10 1/2	1	12	2	12 1/2	3	12 1/2	4	12	4	10	4 1/2	7 1/2	4	5	4	3	4	PM	
	PM	1	4 1/2	0	5 1/2	0	7 1/2	1	9	2	10 1/2	3 1/2	12	4 1/2	12 1/2	5 1/2	12	6	10 1/2	5 1/2	8 1/2	5	6	4 1/2	3 1/2	AM	5
5	AM	4 1/2	1 1/2	5	1/2	6	0	7	1/2	9	2	10 1/2	3	11 1/2	5 1/2	12	6 1/2	11	7 1/2	9 1/2	7	7	6 1/2	4 1/2	5 1/2	PM	
	PM	2	4 1/2	1/2	4 1/2	0	4 1/2	1/2	5 1/2	1 1/2	7	3 1/2	9	6	10 1/2	7 1/2	11 1/2	9	11	9	10	8	8	7	5	AM	6
6	AM	5 1/2	3	4	1	3 1/2	0	4	0	5 1/2	1 1/2	7	3 1/2	9	6	10 1/2	8 1/2	11	10	10 1/2	10 1/2	9	10	6	8 1/2	PM	
	PM	3 1/2	6 1/2	1	4 1/2	0	3	1/2	3	1	3 1/2	3	5	6	7 1/2	9	9	11	10 1/2	12	10 1/2	12	9	10 1/2	7	AM	7
7	AM	8	4	5 1/2	1 1/2	3	0	2	–1	2	0	3	2 1/2	5 1/2	5 1/2	7 1/2	9	9 1/2	12	10	13 1/2	9 1/2	13 1/2	7 1/2	12	PM	
	PM	5	9 1/2	2	6 1/2	0	3 1/2	–1	1 1/2	–1/2	1	1 1/2	1 1/2	5	3 1/2	9	6	12 1/2	8	15	9	15 1/2	9	14 1/2	8	AM	8
8	AM	11 1/2	5	8	2 1/2	4	0	1 1/2	–1 1/2	0	–1	0	1	2	4	4	8 1/2	6 1/2	12 1/2	8 1/2	15 1/2	9	17	8	16	PM	
	PM	5 1/2	13 1/2	2 1/2	10	0	6	–1 1/2	2	–2	0	0	–1	3 1/2	0	8	1	12 1/2	4 1/2	16	7	18	8	18	7 1/2	AM	9
9	AM	15 1/2	6	12	3 1/2	7	1/2	3	1 1/2	0	2 1/2	1 1/2	–1	1 1/2	2	1/2	6 1/2	3	11	5 1/2	15 1/2	7	18 1/2	7	19	PM	
	PM	6	17 1/2	3 1/2	14	1/2	9 1/2	–2	4 1/2	–3	1/2	2	2	1	2 1/2	5	1 1/2	10	1	15	3 1/2	18 1/2	5 1/2	20	6 1/2	AM	10
10	AM	19	5 1/2	16	4	11 1/2	1	6 1/2	–1	2	–3	–1 1/2	–3	3	1	2 1/2	3	1/2	8 1/2	2	13 1/2	4	18	5 1/2	20 1/2	PM	
	PM	5 1/2	20 1/2	4	18	1 1/2	14	–1	8 1/2	–3	3	3	1	–1 1/2	–3	2	3 1/2	7	–2	12 1/2	0	17	2 1/2	20 1/2	4	AM	11
11	AM	21	4 1/2	19	3 1/2	15	1 1/2	10	1	5	3	0	3 1/2	–3	–2 1/2	4	1/2	–3	5 1/2	–1	10 1/2	1	16	3	19 1/2	PM	
	PM	4	21 1/2	3 1/2	20 1/2	1 1/2	17	1	12 1/2	–3	7	–3 1/2	2	–3	–2	0	4	4	4	9	2 1/2	14 1/2	1/2	19	2	AM	12
12	AM	21	3	21	3	18 1/2	2	14	0	13 1/2	–2	3	–3 1/2	–1	3 1/2	3	–1 1/2	4	2	3	7	1 1/2	12	1/2	17	PM	
	PM	2	20	2 1/2	21	1 1/2	19 1/2	0	16	–2	11	–3	6	–3 1/2	1	–2	2	1	4	5 1/2	–3 1/2	10 1/2	2 1/2	15 1/2	–1/2	AM	13
13	AM	19	1	20 1/2	2	20	1 1/2	17	1/2	12	–1	7	2 1/2	2 1/2	–3	–1	2 1/2	–3	0	–3 1/2	4	3	8 1/2	–1 1/2	13	PM	
	PM	0	17	1 1/2	19 1/2	1 1/2	19 1/2	1	17 1/2	1/2	14	2	9 1/2	–3	4 1/2	–2	1/2	0	2	3	–3 1/2	7	3	12	–2	AM	14
14	AM	16	–1/2	18	1	19	1 1/2	18	1	15	0	10 1/2	–1	6	–2	2	–2	–1	–1/2	–3	2	3	6	–2	10	PM	

15	AM	12 −1½	15 0	17 ½	17 1	15½ 1	12½ ½	9 0	5 −½	2 0	−½ 1½	−2 4	−2 7	PM	15
	PM	−1½ 10	−½ 13	½ 15	1 16	1½ 15	1 13	1 10	½ 6½	1 3	2 ½	3½ −1	6 −2	AM	16
16	AM	9 −1½	11½ −1	13½ ½	14½ 1	14½ 1½	13 2	11 2	8 1½	4½ 2	2 2½	0 3½	−1½ 5½	PM	
	PM	−1½ 7½	−1 10	0 12	1 13	2 13½	2½ 13	3 11	3 8½	3½ 5½	3 3	4 1	5 −½	AM	17
17	AM	7 −1	9 −1	10½ 0	12 1	12½ 2	12 3½	11 4	9 4	6½ 4½	4 4½	2 4½	0 5	PM	
	PM	−1 6	−1 7½	0 9	1 10½	2½ 11	4 11½	4½ 11	5½ 9½	5½ 7½	5½ 5	5½ 3	5½ 1	AM	18
18	AM	6 0	7 −½	8 0	9 1	10 2½	10½ 4	10½ 5½	9½ 6½	8 7	6 7	3½ 6½	1½ 6	PM	
	PM	0 6	−½ 6	0 7	1 7½	2½ 8½	4 9	6 9½	7 9	8 8	8 6½	7½ 4½	7 2½	AM	19
19	AM	6½ 1	6 0	6 0	6½ ½	7½ 2	8 4	9 6	9 8	8 9	7 9½	5 9	3 8	PM	
	PM	1½ 7	0 6	0 5½	½ 5½	2 6	4 7	6½ 7½	8½ 8	10 8	10½ 7	10 5½	9 3½	AM	20
20	AM	7½ 1½	6 ½	5½ 0	5 ½	5 1½	6 4	6½ 6½	7½ 9	7½ 11	7 11½	6 11½	4 10	PM	
	PM	2 8½	½ 7	0 5	0 4	1½ 4	3½ 4½	6½ 5½	9 6½	11½ 7	12½ 7	12½ 6	11½ 4	AM	21
21	AM	9½ 2½	7½ 1	5½ 0	4 −½	3½ 1	3½ 3	4½ 6	5½ 9	6½ 11½	6½ 13	6 13½	4½ 12½	PM	
	PM	3 10½	1 8	0 5½	−½ 4	½ 2½	2½ 2½	5½ 3½	9 4½	12 5½	14 6½	14½ 6	14 5	AM	22
22	AM	12 3	9 1	6 0	4 −1	2 0	2 2	2½ 5	3½ 8½	5 11½	5½ 14	5½ 15	5 15	PM	
	PM	3 13	1½ 10	0 7	−1 4	−1 2	1 1	4 1½	7½ 2½	11½ 4	14 5	16 5½	16 5	AM	23
23	AM	14 3½	11½ 1½	7½ 0	4 −1½	2 −1	½ ½	½ 3	1½ 7	3 10	4 14	5 16	4½ 16½	PM	
	PM	3 15	1½ 12½	0 9	−1½ 5	−1½ 2	0 0	3 −½	6½ ½	10½ 1½	14 3	16½ 4	17 4	AM	24
24	AM	16 3½	13 2	9 0	5½ −1½	2 −2	0 −1	−1 1½	−½ 5	1 9	2½ 13	3½ 16	4 17½	PM	
	PM	3 17	1½ 14½	0 11.	−1½ 7	−2½ 3	−1½ 0	1 −1	4½ −1	9 0	13 1	16 2½	18 3½	AM	25
25	AM	17½ 3	15½ 2	12 0	7½ −1½	3½ −2½	0 −2	−1½ −½	−2 3	−1 7	½ 11½	2 15	3 17½	PM	
	PM	2½ 18	1½ 16½	0 13	−1½ 9	−2½ 4½	−2½ 1	−1 −1½	2½ −2½	6½ −2	11 −½	15 1	18 2	AM	26
26	AM	18½ 2½	17 1½	14 0	10 −1½	5 −2½	1 −3	−1½ −1½	−2½ 1½	−2 5½	−1 10	½ 14½	1½ 17½	PM	
	PM	2 18½	1½ 17½	0 15	−1½ 11	−3 6½	−3 2	−2 −1	1 −2½	4½ −2½	9 −1½	13½ −½	17 1	AM	27
27	AM	18½ 1½	18 1½	16 ½	12 −1	7½ −2½	3 −3	0 −2½	−2 0	−3 3½	−2 8	−1 12	½ 16	PM	
	PM	1 18	1 18½	½ 16½	−1 13	−2½ 9	−3 4½	−2½ 1	−½ −1½	2½ −2½	7 −2½	11 −1½	15 0	AM	28
28	AM	18 1	18½ 1	17½ ½	14½ −½	10½ −2	6 −3	2 −2½	−1 −1½	−2½ 1½	−2½ 5½	−2 10	−½ 14	PM	
	PM	½ 17	1 18	½ 17½	−½ 15	−1½ 11½	−2½ 7	−2½ 3	−1½ 0	1 −2	4½ −2½	9 −2	13 −1	AM	29
29	AM	16 0	18 1	18 1	16 0	13 −1	8½ −2	4½ −2½	1 −1½	−1 ½	−2 3½	−2 7½	−1 12	PM	
	PM	0 15	1 17	1 17½	½ 16	0 13½	−1 9½	−2 5½	−1½ 2	0 −½	3 −2	6 −2	10 −1½	AM	30
30	AM	13½ 0	16 ½	17½ 1	16½ 1	14½ ½	11 −½	7 −1	3½ −1	1 0	−1 2	−1½ 5	−1½ 9	PM	
	PM	−½ 12½	½ 15	1½ 16½	1½ 16½	1 14½	½ 12	0 8	−½ 4½	½ 1½	2 −½	4½ −1½	7½ −1½	AM	
31	AM													PM	
	PM													AM	

Table 3

Month: December 1958

		0 h.		1 h.		2 h.		3 h.		4 h.		5 h.		6 h.		7 h.		8 h.		9 h.		10 h.		11 h.			
		12 h.		13 h.		14 h.		15 h.		16 h.		17 h.		18 h.		19 h.		20 h.		21 h.		22 h.		23 h.			
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	105° E	
	75° W	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S		
Dates 1	AM	11	− 1/2	13 1/2	1/2	15 1/2	1 1/2	16	2	15	2	13	1 1/2	9 1/2	1	6	1/2	3	1	1/2	2	−1	4	−1	7	PM	Dates 1
	PM	− 1/2	10	1/2	12 1/2	1 1/2	14 1/2	2 1/2	15	3	14 1/2	2 1/2	12 1/2	2	10	1 1/2	6 1/2	1 1/2	3 1/2	2	1	3 1/2	− 1/2	5 1/2	−1	AM	2
2	AM	8 1/2	− 1/2	11	1/2	13	1 1/2	14	2 1/2	14	3 1/2	13	3 1/2	10 1/2	3 1/2	8	3	4 1/2	2 1/2	2	3	0	3 1/2	− 1/2	5	PM	
	PM	− 1/2	7	0	9 1/2	1 1/2	11 1/2	3	12 1/2	4	13	4 1/2	12 1/2	5	10 1/2	4 1/2	8 1/2	4	5 1/2	4	3	4	1	5	− 1/2	AM	3
3	AM	6	− 1/2	8	0	9 1/2	1 1/2	11	3	12	4 1/2	12	5 1/2	11	6	9	6	6 1/2	5 1/2	4	5	1 1/2	5	0	5	PM	
	PM	− 1/2	5 1/2	0	6 1/2	1	8	2 1/2	9 1/2	4 1/2	10 1/2	6	11	7 1/2	10 1/2	8	9	7 1/2	7	7	4 1/2	6	2	5 1/2	1/2	AM	4
4	AM	5	− 1/2	5 1/2	− 1/2	6 1/2	1/2	7 1/2	2	8 1/2	4	9 1/2	6 1/2	9 1/2	8	9	9	7 1/2	9 1/2	5	8 1/2	3	7 1/2	1	6	PM	
	PM	− 1/2	5	−1	5	0	5	1 1/2	5 1/2	4	7	6 1/2	8	9	8 1/2	10 1/2	8 1/2	11	7 1/2	10 1/2	5 1/2	9	3 1/2	7 1/2	1 1/2	AM	5
5	AM	6	0	4 1/2	−1	4	−1	4	1/2	5	3	6	6	7	9	7 1/2	11	7	12 1/2	6	12 1/2	4	11 1/2	2	9	PM	
	PM	0	7	−1	5	−1	3 1/2	0	2 1/2	2 1/2	3	5 1/2	4	9	5 1/2	12	6	14	6 1/2	14	6	13	4	11	2	AM	6
6	AM	8	0	5 1/2	−1	3 1/2	−2	2	−1	2	1	2 1/2	4 1/2	3 1/2	8	5	11 1/2	5 1/2	14 1/2	5 1/2	15 1/2	4 1/2	15	2 1/2	13	PM	
	PM	1/2	10 1/2	−1 1/2	7	−2	4	−2	1 1/2	0	1/2	3 1/2	1	7 1/2	1 1/2	11 1/2	3	15	4	17	5	17	4	15	3	AM	7
7	AM	12	1/2	8	−1	4 1/2	−2 1/2	1 1/2	−2 1/2	0	−1	− 1/2	2 1/2	0	6 1/2	1 1/2	11	3	15	4	17 1/2	4	18	2 1/2	17	PM	
	PM	1	14	−1	10	−3	5 1/2	−3 1/2	2	−2	−1	1/2	−2	5	−1 1/2	9 1/2	0	14	1 1/2	17 1/2	3	19	3 1/2	18 1/2	2 1/2	AM	8
8	AM	16	1	12	−1	7	−2 1/2	3	−3 1/2	− 1/2	−3	−2 1/2	−1	−2 1/2	3 1/2	−1 1/2	8	0	13	2	17	2 1/2	20	2 1/2	20	PM	
	PM	1	18	−1	14	−3	9	−4	4	−4	0	−2	−3	2	−3 1/2	6 1/2	−3	12	−1 1/2	16 1/2	1/2	20	2	21	2 1/2	AM	9
9	AM	19 1/2	1 1/2	16	0	11	−2	6	−4	1	−4 1/2	−2 1/2	−3	−4	0	−4	4 1/2	−2 1/2	10	−1	15	1	19	2	21	PM	
	PM	1 1/2	20 1/2	0	18	−2	13	−4	7 1/2	−4 1/2	2 1/2	−4	−1 1/2	−1 1/2	−4	3	−4 1/2	8	−3 1/2	13 1/2	−2	18	0	21	1 1/2	AM	10
10	AM	21 1/2	1 1/2	19	1/2	15	−1 1/2	10	−3	4	−4 1/2	0	−4 1/2	−3 1/2	−2 1/2	−5	1 1/2	−4 1/2	6 1/2	−3	12	−1	17	1/2	20	PM	
	PM	1	21 1/2	1/2	20	− 1/2	16	−3	11 1/2	−4	6	−4 1/2	1	−3	−3	0	−5	4 1/2	−5	10	−3 1/2	15	−1 1/2	19	0	AM	11
11	AM	21	1	21	1	18	0	13 1/2	−2	8	−3 1/2	2 1/2	−4 1/2	−1 1/2	−3 1/2	−4	−1	−5	3	−4	8	−2 1/2	13	− 1/2	18	PM	
	PM	1	20 1/2	1	21	1/2	18 1/2	−1	14 1/2	−3	9 1/2	−4	4	−3 1/2	− 1/2	−2	−3 1/2	1 1/2	−4	6	−4 1/2	11	−3	16	−1	AM	12
12	AM	19	1/2	20 1/2	1 1/2	19	1	16	0	11	−2	6	−3	1 1/2	−3 1/2	−2	−2	−4	1/2	−4 1/2	5	−3 1/2	9 1/2	−1 1/2	14	PM	
	PM	0	18	1 1/2	19 1/2	1 1/2	19	1/2	16 1/2	−1	12 1/2	−2	7 1/2	−2 1/2	3	−2	−1	0	−3 1/2	3 1/2	−4	8	−3 1/2	12	−2	AM	13
13	AM	16	0	18	1 1/2	19	2	17	1 1/2	14	0	9	−1	4 1/2	−1 1/2	1/2	−1 1/2	−2	0	−3 1/2	3	−3 1/2	7	−2	11	PM	
	PM	− 1/2	14 1/2	1	17	2	18	2	16 1/2	1 1/2	14	0	10	− 1/2	5 1/2	−1	1 1/2	0	−1 1/2	2	−3	5	−3	9	−2	AM	14
14	AM	13	0	15 1/2	1	17	2 1/2	16	3	14	2 1/2	10	1 1/2	6	1/2	3	0	0	1/2	−2	2	−2 1/2	5	−2	8	PM	

15	AM	10 −1	12 1	14 2½	14½ 3½	13½ 4	11 4	8 3	5 2½	2 2½	−½ 3	−1½ 4	−1½ 6	PM	15
	PM	−½ 8½	1 11	2½ 12½	4 13	4½ 13	5 11	4½ 9	4 5½	3½ 3	4 ½	4½ −1	6 −1	AM	16
16	AM	8 −½	9½ 1	11 2½	12 4	12 5	11 5½	8½ 5½	6 5½	3½ 5	1 5	0 5	−1 6	PM	
	PM	−½ 7	½ 8½	2 10	4 11	5 11	6 10	6½ 8½	6½ 6½	6 4	6 2	6 0	6 −½	AM	17
17	AM	7 −½	8 ½	9 2	9½ 3½	10 5½	9½ 6½	8 7½	6½ 8	4½ 7½	2½ 7	1 6½	0 6½	PM	
	PM	−½ 6½	0 7	1½ 7½	3 8	5 8½	7 8½	8 8	9 6½	9 5	8½ 3	8 1	7 0	AM	18
18	AM	7 −½	6½ 0	7 1	7 3	7½ 5	7½ 7	7 8½	6 9½	5 10	3 9½	1½ 9	½ 8	PM	
	PM	−½ 7	−½ 6½	1 6	2 6	4½ 6½	6½ 6½	8½ 6½	10 6	11 5	11 3½	10 2	9 ½	AM	19
19	AM	7½ −½	6½ −½	5½ ½	5½ 2	5 4	5½ 6½	5½ 9	5 10½	4½ 12	3½ 12	2 11	1 9½	PM	
	PM	0 8	−1 6½	−½ 5½	1 4½	3 4	5½ 4	8 4½	10½ 4½	12 4	13 3½	12 2	11 1	AM	20
20	AM	9 0	7 −1	5 −½	4 ½	3½ 2½	3 5	3½ 8	4 11	4 12½	3½ 13½	2½ 13½	1 12	PM	
	PM	0 10	−1 7½	−1 5	0 3½	1½ 2½	4 2	7 2½	10 3	13 3½	14 3	14 2½	13 1	AM	21
21	AM	11 0	8 −1	5½ −1½	3 −1	2 1	1½ 3½	1½ 7	2 10	2½ 13	3 14½	2½ 15	1½ 14	PM	
	PM	0 12	−1 9	−2 6	−1½ 3	0 1½	2 ½	5½ ½	9 1	12½ 2	15 2½	16 2	15 1½	AM	22
22	AM	13 0	10 −1	7 −2	3½ −2	1 −1	0 1½	−½ 5	0 8½	1 12½	1½ 15	2 16½	1½ 16	PM	
	PM	½ 14	−1 11	−2 7½	−2½ 4	−2 1	0 −½	3½ −1	7½ −1	11½ 0	14½ 1	16½ 1½	17 1½	AM	23
23	AM	15 ½	12 −1	8 −2	4½ −2½	1 −2	−1 −½	−2 3	−1½ 6½	−½ 11	½ 14½	1 17	1 17½	PM	
	PM	½ 16	−1 13½	−2 9½	−3 5½	−2½ 1½	−1 −1	2 −2	5½ −2½	10 −1½	14 0	17 1	18 1	AM	24
24	AM	17 ½	14½ −½	10½ −2	6 −3	2 −3	−1 −2	−2½ ½	−3 4½	−2 9	−1 13	½ 16½	1 18½	PM	
	PM	½ 18	0 16	−2 12	−3 7½	−3½ 3	−2½ 0	0 −2½	3½ −3	8 −2½	12½ −1½	16 0	18½ 1	AM	25
25	AM	19 1	17 0	13½ −1½	9 −3	4½ −3½	½ −3	−2 −1	−3½ 2½	−3 7½	−2 12	−½ 16	½ 18½	PM	
	PM	1 19	½ 17½	−1 14	−2½ 10	−3 5	−3 1	−2 −2	1 −3½	5½ −3	10½ −2	14½ −1	18 ½	AM	26
26	AM	19½ 1	19 ½	16½ −½	12 −2	7½ −3	2½ −3	−1 −2	−3 ½	−3½ 5	−2½ 9½	−1 14	0 17½	PM	
	PM	1 19½	1 19	½ 16½	−1 12½	−2½ 8	−3 3	−2½ −½	−½ −3	3 −3½	7 −3	12 −1	16 0	AM	27
27	AM	18½ 1½	19½ 1½	18 1	15½ −½	11 −2	6 −3	1 −2½	−2 −1	−3 2½	−3 7	−2 11½	0 15½	PM	
	PM	1½ 18	2 19	1½ 18	½ 15	−1 10½	−2 6	−2½ 2	−1½ −1½	1 −3	5 −3	9 −1½	13½ 0	AM	28
28	AM	17 1½	19 2½	18½ 2½	16 1	12½ 0	8 −1½	3½ −2	0 −1½	−2 1	−2½ 4½	−2 9	0 13	PM	
	PM	1½ 16½	2½ 18	3 18	2½ 16	1 13	−½ 8½	−1½ 4	−1 ½	0 −1½	3 −2½	6½ −2½	10½ 0	AM	29
29	AM	15 1½	17 3	18 3½	16½ 3½	13½ 2	9½ 1	5 0	1½ −½	−1 ½	−2 2½	−1½ 6	0 10	PM	
	PM	1½ 13½	3 16	4 17	4 16	3½ 14	2 10½	1 6½	½ 3	½ 0	2½ −1½	5 −1½	8½ −½	AM	30
30	AM	12 1½	14½ 3	16 4½	15½ 5	14 4½	11 3½	7 2½	3½ 1½	½ 1½	−1 2	−1½ 4	−½ 7	PM	
	PM	1 10	3 12½	5 14½	5½ 15	5½ 13½	5 11	4 8	2½ 4½	2 1½	2½ −½	4 −1	6 −½	AM	31
31	AM	8½ 1	11 3	13 5	13½ 6	13 6½	11 6½	8 5½	5 4½	2 3½	0 3	−1 3½	−1 5	PM	
	PM	½ 7	2 9	4½ 11	6 12	7½ 12	7½ 10½	7 8	6 5½	5 2½	4 ½	4 −1	4½ −1	AM	